Proceedings of a Workshop on Possible Pathways of Cadmium into the Pacific Oyster (*Crassostrea gigas)* as Cultured on the Coast of British Columbia, Institute of Ocean Sciences, March 6-7, 2001

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PROCEEDINGS OF A WORKSHOP ON POSSIBLE PATHWAYS OF CADMIUM INTO THE PACIFIC OYSTER (*Crassostrea gigas)* AS CULTURED ON THE COAST OF BRITISH COLUMBIA, INSTITUTE OF OCEAN SCIENCES, MARCH 6-7, 2001.

by

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LIST OF ACRONYMS AND ABBREVIATIONS

ADI	Acceptable Daily Intake
AMMA	Active Malaspina Mariculture Association
BCSGA	BC Shellfish Growers Association
CAC	Codex Alimentarius Commission
CCFAC	Codex Committee on Food Additives and Contaminants
CFIA	Canadian Food Inspection Agency
CHS	Canadian Hydrographic Service
CODEX	Codex Alimentarius of the FAO/WHO (International Food Code)
CSSP	Canadian Shellfish Sanitation Program
DFO	Department of Fisheries and Oceans
EC	Environment Canada
FAO	Food and Agriculture Organization of the United Nations
FAU	Florida Atlantic University
FBO	Fanny Bay Oysters
HACCP	Hazard Analysis Critical Control Point
HC	Health Canada
ICPMS	Inductively Coupled Plasma Mass Spectrometry
HEB	Habitat Enhancement Branch, DFO
IOS	Institute of Ocean Sciences, DFO
JECFA	Joint FAO/WHO Expert Committee on Food Additives
MAFF	Ministry of Agriculture Food and Fisheries, BC.
MEHSD	Marine Environment and Habitat Science Division, DFO
NRCAN	Natural Resources Canada
OCAD	Office of the Commissioner of Aquaculture Development
OSAP	Ocean Science and Productivity Division, DFO
PFC	Pacific Forestry Center
PSARC	Pacific Scientific Advice Review Committee, DFO
PTWI	Provisional Tolerable Weekly Intake
RGS	Regional Geochemical Survey
SEOS	School of Earth and Ocean Sciences
SFU	Simon Fraser University
SQCRD	Skeena Queen Charlottes Regional District
UBC	University of British Columbia
UVIC	University of Victoria
WHO	World Health Organization

ABSTRACT

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On 6-7 March, 2001 approximately 40 invited participants from Canada, the USA, New Zealand, Australia and Mexico gathered at the Institute of Ocean Sciences in Sidney, BC to exchange information on the possible sources of cadmium in BC cultured oysters. This report comprises informal proceedings of this exchange and includes an outline of ideas for discussion, Abstracts provided by the 29 speakers, as well as their presentations on a CD-ROM. A synthesis of the discussions includes the identification of data gaps and contains recommendations on directions for future research.

RÉSUMÉ

Kruzynski, G.M., R.F. Addison, and R.W. Macdonald. 2002. Proceedings of a workshop on possible pathways of Cadmium into the Pacific Oyster (*Crassostrea gigas)* as cultured on the coast of British Columbia, Institute of Ocean Sciences, March 6-7, 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2405: vi + 65pp.

Les 6 et 7 mars 2001, environ 40 experts du Canada, des États-Unis, de la Nouvelle-Zélande, de l'Australie et du Mexique se sont rassemblés, sur invitation, à l'Institut des Sciences de la Mer de Sidney, en Colombie-Britannique, pour échanger des informations sur les sources possibles du cadmium dans les huîtres de culture de cette province. Ce rapport contient les comptes rendus informels des échanges qui eurent lieu, un cenevas d'idées pour discussion, les résumés des exposés de 29 conférenciers, ainsi que leurs présentations sur disque compact. Une synthèse des discussions inclut l'identification des données encore à acquérir et des recommandations sur les orientations futures de la recherche.

INTRODUCTION

In response to a May, 2000 request by the Canadian Food Inspection Agency (CFIA) the Department of Fisheries and Oceans (DFO), Pacific Region undertook to investigate the potential reasons for apparently elevated Cadmium levels in BC cultured Pacific oysters *Crassostrea gigas*. Earlier in the year, CFIA reported that several shipments of BC farmed oysters had been rejected by the Hong Kong Food and Environmental Hygiene Department as being in excess of their 2 μg Cd/g (ppm) wet weight limit. A preliminary literature search was conducted, contacts were made with BC shellfish growers and processors, both government and academic researchers were consulted and the resulting information was synthesized by GMK in the form of a PSARC (Pacific Scientific Advice Review Committee) report: *Cadmium in BC farmed oysters: A review of available data, potential sources, research needs and possible mitigation strategies*

(http://www.pac.dfo-mpo.gc.ca/sci/psarc/ResDocs/Habitat_00.htm)

Among recommendations of the PSARC report was the holding of a Cadmium and Oysters Workshop to exchange information with oceanographers, geologists, geochemists, oyster growers, toxicologists, biochemists and biologists; the objective being to define fruitful avenues of research and possible mitigative strategies. These are the Proceedings from that Workshop.

WORKSHOP OBJECTIVES

1. Disseminate information gathered by Canadian Food Inspection Agency (CFIA) in 2000.
2. Provide status report on what information DFO Science has assembled in relation to CFIA data provided to us in May 2000.
3. Seek clarification of Health Canada and CFIA's role.
4. Provide opportunity for input from BC Shellfish Growers Association (BCSGA), Growers Coops, and individual oyster farmers.
5. Seek advice on logistics of proposed grow-out experiment: common stock of oyster distributed to various sites to be sampled after a year of suspension culture.
6. Provide a forum for exchange of scientific information which might be utilized to clarify and perhaps define potential Cd pathways.
7. Formulate ideas for potential collaborative research projects with the objective of generating an interdisciplinary proposal for FY 2002-2003.

ORGANIZATION

Literature work and discussions led to the formulation of general hypotheses and ideas. These are presented below as *Potential sources and Factors Influencing Cadmium Uptake in Oysters*. Contacts were established with specialists at the University of British Columbia, Simon Fraser University in Vancouver, University of

Victoria and University of Northern British Columbia in Prince George. These researchers as well as federal and provincial government contacts and industry representatives were invited to elaborate on these topics in the context of addressing cadmium pathways into bivalves, regulatory and health aspects, as well as methodologies that could be applied in mounting a research effort to address data gaps.

The workshop was held Tuesday March 6th and Wednesday 7th, 2001, with the Agenda as indicated on page 13. Minor scheduling modifications were necessary to accommodate a few speakers, but in general, presentations were grouped by topic. The first day dealt with the roles of various government departments, BC 's plans for expansion of shellfish culture, and the terrestrial component including remote sensing. The second day was devoted to oceanography, physiology and biochemistry of Cd uptake and storage.

A Wednesday evening session was held to discuss and synthesize information that was exchanged. The objective was to identify data gaps, define what would be useful to collect or assemble from existing knowledge, consider the possible applicability of remote sensing as well as investigate the potential for interdisciplinary proposals for research to gather new information and to identify potential funding sources.

A draft summary was prepared by R. Addison, R. Macdonald, E. Black and G. Kruzynski and circulated to participants after the workshop. Comments received were incorporated and this synthesis is presented in the Summary and Discussion (p. 4) and in Recommendations for Research (p. 8)

Thirty-one presentations were made by 29 speakers. GMK made several short presentations between speakers to facilitate continuity. Dr. Keith Hunter of University of Otago, New Zealand, whose travel was inadvertently cancelled due to severe winter weather, kindly provided a copy of his talk and this is included in the set. Mr. H. Nelson of Environment Canada presented data (Nelson and Goyette 1976) that had already been synthesized by GMK, (Appendix Fig. 2) so is not included separately.

Authors were asked to provide copies of their presentations in Microsoft PowerPoint™ format and these have been reproduced with minimal editing in CD-ROM format in Appendix A which also contains the set of maps distributed by GMK at the workshop. Abstracts provided by authors begin on page 21. A list of the approximately 40 participants is presented in Appendix B and provides contact information.

POTENTIAL SOURCES AND FACTORS INFLUENCING CADMIUM UPTAKE IN OYSTERS

Aquatic

Oceanographic/Food Chain

- Vertical transport by upwelling of phosphate and Cd from deeper waters
- Horizontal transport by currents

- Influence of salinity and temperature
- Preferential uptake by plankton during blooms; possible influence of zinc limitation
- Pathway to oysters via food supply
- Evidence for a latitudinal Cd gradient

Terrestrial

Geology/Geochemistry

- Local mineralogy
- Sequestration by hematite
- Contribution of glacial flour

Agriculture

- Cd contaminated phosphate fertilizers

Forestry Practices

- Wholesale forest canopy removal, soil erosion, exposure of bedrock, increased leaching
- Fertilizer application at reforestation

Other Sources

- Municipal STP's (sewage treatment plants)
- Pulp mills
- Fertilizers applied to golf courses
- Septic sludge
- Plastics with Cd as pigment/UV stabilizer utilized in oyster culture

Biological Factors

- Unnatural feeding regime during suspension culture
- Resuspension and re-ingestion of accumulating waste
- Sequestration by anoxic sediments
- Uptake controlled by salinity

QUESTIONS

General

- Is this new?
- What are the contributing factors?
- Is it a health risk?
- What can be done about it?

Scientific

- What is known about differences in Cd uptake by phytoplankton of importance to the oyster diet?
- What seasonal data do we have on phosphate?
- Utility of BC Regional Geochemical Survey (RGS) stream sediment Cd data?

- Is there a potential application for remote sensing and satellite images?

SUMMARY AND DISCUSSION

General background

The issue of Cadmium (Cd) in Pacific oysters cultured in BC arose in early 2000 after three successive batches were rejected by the Hong Kong Food and Environmental Hygiene Department in December 1999, January and February 2000, as their Cd concentrations exceeded the 2 ppm (2 μg/g) wet weight (ww) standard applied there. The workshop whose proceedings are summarised here was organised to exchange information about the industry, to discuss possible reasons for Cd accumulation by Pacific oysters, and to seek practices or processes which might mitigate the problem. The participants included shellfish growers, scientists and regulators from federal and provincial government departments, and scientists from academia.

The value of the Pacific oyster industry in BC is about $15M annually (1996-1997 data: Carswell 2001) and it provides employment for about 1000 individuals. Approximately 17% of production is consumed domestically, another 17% is exported to the Far-east (half to Hong Kong) and the balance (about 65%) is exported to the USA (the value of the Hong Kong market is therefore about $2M).

Although these figures are not large compared to the value of total landed fishery catch in Canada, they are disproportionately significant to coastal communities where few employment opportunities exist. The shellfish industry has the potential to grow to a value of about $100M. The industry is managed and regulated domestically by many federal and provincial agencies. However, despite the complexity of the regulatory structure, all the key players seem to work well together. The concentration of Cd in BC Pacific oysters, which is usually around or over 2 μg ww, is not at present a domestic issue, as Health Canada has no guidelines for Cd consumption by the Canadian consumer. However, both domestic and international markets would be seriously affected if Canada and export markets were to adopt the Codex rules now being discussed which could lead to a recommended concentration limit of 1 μg/g ww. Currently, the USA recommends that Cd concentrations in Pacific oysters should not exceed 3.7 μg/g ww. However, Canada usually "aligns" itself eventually with the Codex standards.

A "back-of-envelope" calculation illustrates the level of exposure one might expect from the consumption of oysters. A 300 g meal of oysters (6 x 50g) at 2 μg/g ww Cd would provide a dose of 600 μg Cd –about 50% over the WHO recommended adult weekly intake (385 μg) from all including non-food sources. This is probably not an issue for most Canadians consumers given the safety factors incorporated into recommended intakes, but it would be significant to consumers for whom oysters are an important dietary component.

The Codex standard is based on considerations of human health and safety, although economic factors are also taken into account. Codex negotiations are now at Step 3; at Step 6, countries *and organisations* can comment on draft standards.

In summary, *if the Codex standard becomes 1 µg/g (ww) and the US adopts it, Canada's main export market for Pacific oysters would close. It follows that the British Columbia Shellfish Growers Association (BCSGA) and other interested parties should maintain a vigilant watch on Codex negotiations and be prepared to comment at Step 6.*

Distribution of Cd in Pacific oysters — possible sources and pathways

Several participants at the workshop presented data describing Cd concentrations in oysters and other cultured shellfish. The data occasionally appeared contradictory, probably due to factors we presently do not adequately understand, so the following should be recognised as a *general* summary. A limited survey of Cd in BC oysters was undertaken by DFO and BC Fisheries during the summer of 2000 with sites selected to provide insight into variables such as history, growing conditions, age, and size. When completed, the analytical data from this survey may prove helpful in fine tuning some of research directions recommended at this workshop.

Cadmium concentration is usually related to age or size of the animal; *concentrations* may decrease with increasing size ("growth dilution") though *burdens* (total Cd contained in a given oyster) increase with size (Thomson 1982; Kruzynski 2001). Concentrations in oysters appear to be independent of culture method (Schallie 2001), though one study (from Tasmania) suggests that concentrations may be higher in oysters living on bottom sediments (Thompson 2001). However, other studies (McConachie and Lawrance 1991; Thomson 1982; Hayes et al. 1998) revealed no such difference; i.e. sediment Cd was not correlated to that in oysters.

There appears to be a slight trend of increasing Cd concentration from south to north in BC cultured oysters from the Strait of Georgia. Cd concentrations seem not to have declined from the early 1970s to the present, though this conclusion is tentative as it is based on a comparison between wild and cultured oysters. The lack of evidence of any decline in Cd concentrations over this interval contrasts the situation for the southeast US and the Gulf of Mexico, where Cd concentrations in *Crassostrea virginica* (used as a "sentinel" organism in the US "Mussel Watch" – for example see Baliaeff et al.1997) have declined steadily in response to reduced industrial and urban discharges. This suggests that Cd in BC oysters is not related industry but rather derives from natural processes, which is consistent with the absence of industry or urbanisation near the growing areas. This in turn implies that BC oysters could correctly be referred to as "enriched in", but not "contaminated by" Cd; an important point when considering any future action to mitigate such enrichments.

The most probable source of Cd to the oysters is their food: phytoplankton and other filtered particulates (Reinfelder et al. 1997), though direct uptake from water may also

contribute. Data from Lares (2001) suggests that in (e.g.) *Mytilus californianus*, Cd concentrations in tissue can fluctuate in concert with water concentration. Eventually Cd in oysters becomes bound to a specific protein (metallothionein, MT: Kohler and Riisgard 1982; Roesijadi 1996) and the Cd-MT complex turns over very slowly (the half life of Cd in Cd-MT in *C. virginica* gills is of the order of 80 d, Roesijadi 2001). There appear to be no data describing Cd concentrations in local phytoplankton; however, Cd concentrations in surface sea water in the NE Pacific have been documented, and are about 3-fold higher than in surface waters of the NW Atlantic (Crispo 2001). The deeper waters of the Pacific that upwell along BC's coast and supply nutrients to support phytoplankton growth, are also relatively enriched in Cd.

Land-based *natural* occurrences of Cd cannot be eliminated as sources, especially since the surfical geological structures of coastal BC are rich in Zn-containing minerals with which Cd is usually associated (Lett and Jackaman 2001). However, no estimates of "loadings" of Cd from streams or rivers to shellfish growing areas have been made. It is also possible that alteration in terrestrial systems by human activities such as occur during mining, road construction, forest clear-cutting or farming could have led to increased surface run-off or altered patterns of runoff, but it is not known whether such alterations are a significant source of Cd in any location. Phosphate fertiliser, which inevitably contains Cd (Elinder and Järup 1996), is widely used (e.g., in agriculture, silviculture (Brown 2001) and for golf courses) and the application of phosphate could, therefore, supply Cd to estuaries through runoff. We have no data for the Fraser Valley or other areas and further work to determine the significance of this as a potential Cd source is clearly warranted.

Taking these points together, we draw the following general conclusions about possible sources and pathways that lead to Cd accumulation by cultured Pacific oysters.

1. Cd is enriched in the North Pacific Ocean relative to the Atlantic simply as part of the natural global ocean nutrient cycle. Cd mimics phosphorus in the ocean because it follows the soft-body parts of plankton during remineralization and therefore becomes elevated in waters exhibiting high nutrients (Bruland and Franks 1983). For BC, nutrient- and Cd-enriched water is upwelled along the coast especially during summer when winds are from the north (Freeland and Denman 1982; Mackas et al. 1987). Upwelled water also provides the source for much of the nutrient supply for the marginal basins of the coast including the Strait of Georgia and coastal inlets (Harrison et al. 1991; Stucchi 2001; Whitney 2001). Due to this higher natural Cd concentration, it seems probable that Cd would be accumulated to a greater degree by phytoplankton, particularly during blooms, and there is some evidence that Cd may partially replace Zn if the latter is depleted in sea-water, both in phytoplankton (Lane and Morel 2000; Price and Morel 1990) and in bivalves (Sunda and Huntsman 2000). In Japan, the highest levels of Cd were found in mussels *Septifer virgatus* that had the lowest levels of Zn and it was suggested (Y. Shibata personal communication 2000) that this bivalve was able to accumulate Cd instead of Zn when Zn depletion occurred. The phytoplankton-associated Cd would then be accumulated by feeding

oysters, and fairly rapidly scavenged by metallothionein and sequestered as a complex with a slow turn-over rate.

Local factors may play an important –or even crucial –role in the uptake of Cd by oysters. For example, runoff in some coastal streams may be enriched in Cd especially in locations exhibiting high mineralization or upland watershed disturbance. If this Cd is labile (available) it could be accumulated in oysters as part of the particulate food they consume provided the oysters do not selectively reject such material. It is also possible that a partitioning onto particles plays a role wherein a mineral such as haematite (Fe_2O_3; red iron ore) can provide an intermediary that acts as an efficient –and re-usable –Cd pathway from water to mineral surface to oysters through filter feeding (McConchie and Lawrance 1991). Since beach sands in BC often contain haematite, this remains a possible, but unevaluated, pathway. Another speciation possibility are iron-oxy-hydroxides formed as floc at the freshwater-marine interface. These provide a very large surface area and are known to sequester other metals, particularly in ionic form and as metallo-organic complexes associated with the dissolved organic carbon (DOC) component of freshwaters. If this is the case, then factors such as the Fe, DOC and Cd content of the freshwater and the Cd content of the marine waters may be critical issues affecting the resulting chemistry of the suspensates that might be ingested by the shellfish. (Garrett, R. personal communication, NRCAN).

2. Other components of the water, for example dissolved organic carbon (Guo et al. 2001) may affect metal uptake. In Australian waters a correlation has been observed between Cd in oysters and Cd in the sediments on which they rest (Thompson 2001). In such a case, there might be a pathway that operates by enriching Cd in sediments through redox chemistry (cf. Pedersen et al. 1989) and then releasing this Cd to oysters via resuspension.

3. Finally, it is possible that there is a complex interaction between some or all of these processes that depends critically on seasonal cycles which vary from location to location. For example, rivers on Vancouver Island tend to peak during autumn whereas coastal (Mainland) rivers which drain large glaciers and snowfields tend to peak in June. Particle loads (e.g. glacial flour perhaps enhanced in Cd) and salinity stratification produced locally by these rivers would interact differently with the oyster's physiology and thereby affect Cd uptake.

The three pathway components delivering Cd to northeastern Pacific oysters about which we are most confident –global ocean cycle, upwelling, and the oyster's proclivity to accumulate Cd –are also the three that we can do little to change. The complex local or regional factors listed above may provide clues to identify poor sites for oyster culture or poor times to harvest oysters, but at present we have few data with which even to test hypotheses.

If the factors listed above turn out to be the major controls for Cd in BC oysters, there are several implications:

1. Cd accumulation should be a feature not just of cultivated oysters, but also wild oysters, and, indeed, any filter-feeding organism (though shellfish are probably the most important commercially). Regardless of the uptake process, Cd is sequestered as a Cd-MT complex which has a slow turn-over rate.

2. The slow turnover of Cd-MT makes it unlikely that high Cd concentrations could be "depurated" by holding the oysters in clean water (assuming reasonably Cd-free sea-water would be available). Mitigation of the problem should therefore be based on other strategies, such as harvesting before the spring plankton blooms, or in the cases where the Cd can be shown to be present in inorganic constituents of the food, e.g. from upland sources, avoidance of such sites may be necessary.

3. The behaviour of Cd tends to mimic that of phosphate in the ocean; since nutrient supply fuels the phytoplankton blooms on which the oysters feed, selection of sites of high biological productivity actually selects for high Cd supply. However, if Cd accumulation by phytoplankton depends to some extent on Zn depletion, this is most likely to occur towards the end of a bloom; thus exposure to Cd might be reduced by monitoring the progress of a bloom.

These points suggest directions for further work focussed mainly on the components of the Cd pathway that we do not understand at present.

RECOMMENDATIONS FOR FURTHER RESEARCH

Among the studies that should be carried out in the short term:

(a) Address the hypothesis that *Cd accumulation by cultured oysters reflects Cd uptake by phytoplankton during a bloom, and specifically the relationship between Cd and Zn uptake by phytoplankton.* Requires frequent (1-2x/week) sampling of phytoplankton and oysters at 2 -3 selected sites during a bloom and analysis for Chl a, Zn and Cd. Some of these data may be available through remote sensing (Borstad 2001).

(b) Define the relative importance of oceanic (via upwelling) and local riverine and run-off sources of Cd by contrasting uptake of Cd in oysters from locations influenced by streams that are Cd enriched with those where nearby streams are not Cd enriched. Gut contents partitioning into organic and inorganic constituents would help define the pathways.

(c) Investigate the relationship between Cd in sediments (both suspended and deposited) and Cd in oysters (evidence presently available suggests that there is no such correlation but further data should be collected as an extension to the recent oyster survey). Additionally, elemental scans available with ICP-MS could be used to seek relationships between Cd and other elements. In the list of hypothetical contributors to Cd enrichment in oysters have been included 1) the food web; both organic and inorganic, 2) surface

adsorption and 3) redox enrichment. Each of these processes enriches elements differently depending on their biogeochemistry (e.g., conservative, recycled, scavenged) and the signature of the important process might show up in the oysters themselves (a cheap and uncertain fishing expedition).

(d) In some coastal inlets, e.g. Effingham Inlet (Barkley Sound, Fig.1f) there may well be a lateral salinity gradient from the head seaward at least in the surface waters where oysters are suspended. Grow-out oysters could be deployed along this gradient. Of course, if there are also mineral deposits, and logged areas these could be acting in concert. A desktop exercise could be carried out to define these from LANDSAT (Burt and Snijders 2001) and RGS (Regional Geochemical Survey) data as well as from any salinity data that might exist.

(e) Determine locations on the BC coast where wild oysters can still be collected. Such sampling should coincide with the 1973 Environment Canada sites (Figure 1 Appendix) which generated baseline data on wild oysters. A comparison of current Cd wild oyster residues would serve to determine temporal trends and whether the suggested latitudinal gradient still persists.

For longer term studies

(f) Establish whether there is a relationship between Cd uptake and Zn availability and, if so, attempt to manage the Cd/Zn uptake relationship in phytoplankton by "fertilising" a bloom at an oyster rearing site with Zn. A pilot laboratory culture experiment should precede this effort.

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AGENDA

Oyster and Cadmium Workshop
Agenda for Tuesday, March 6th and Wednesday, March 7th 2001

Titles in bold, topics suggested to authors in italics.

08:30-09:30 **Registration**

09:30-10:00
George M. Kruzynski, IOS. **Cadmium in BC Cultured Oysters: An Overview**
Introduction. Outline of events, Cadmium use, potential cadmium sources, PSARC Workshop plan.

10:00-10:30
Brian Kingzett, Kingzett Professional Services, Duncan, BC. **The Shellfish Culture Industry in British Columbia.**
History, current and future species, economics, general overview and comparison of production methods and materials.

GMK 1 slide* (materials leaching results)

10:35-10:45
William F. Dewey Taylor Shellfish Co., WA. **Cadmium in Taylor Shellfish Company Oysters, Washington USA**

Quick overview of Cd data from longline vs bottom culture in two locations in Puget Sound.

10:45-11:15
William A. Heath and Barron Carswell BC Fisheries, Courtenay and Victoria resp.: **Site Selection Considerations for Shellfish Farming in British Columbia** &
The BC Shellfish Development Initiative Process and the Relevance of Cadmium concentration data in BC cultured oysters to Industry Development (respectively).

Historical background of Industry, Shellfish Development Initiative, site selection protocols, future expansion plans.

GMK 2 slides* (Fish farms/oyster lease interaction)

11:15-11:30 **COFFEE BREAK**

11:30-11.45
Sheila Dobie, SQRCD, Prince Rupert: **Notes on the North Coast Shellfish Industry, April 2001.**
Skeena Queen Charlotte Regional District (Prince Rupert): Northern expansion plans including growing interest by First Nations.

GMK 2 slides* (Comparison of Cadmium and Zinc residues among Species)

12:00-12:15

Ruth Salmon, Executive Director BCSGA **How Industry Sees the Cadmium Issue.**

Perspectives on the issue of the BC Shellfish Growers Association representing some BC oyster growers, relationship to CFIA.

12:15-12:30
Allison Webb, DFO. **Shellfish Monitoring Project.**
Role of the Office of the federal Commissioner of Aquaculture

12:30-13:00 **LUNCH Provided**

13:00-13:30
Sing Liem CFIA Burnaby. **CFIA's Role in Food Safety Matters**
Klaus Schallie, CFIA Burnaby: **Results of the 2000 Survey of Cadmium in BC oysters.**

CFIA mandate in relation to DFO and Health Canada, results of 2000 CFIA processor survey (mapped by GMK)

13:30-13:45
Hal Nelson Environment Canada. **Historical and Present EC Involvement in Shellfish Programs.**

EC historical Cd data mapped by GMK.

13:45-14:00
Wayne Knapp DFO RHQ Vancouver, Habitat Enhancement Branch.
Cadmium in Shellfish, Habitat Management Roles and Responsibilities.

DFO HEB mandates from a habitat protection and human health standpoint. Relationship with Health Canada and CFIA.

14:00-14:30
Kevin Telmer University of Victoria, School of Earth and Ocean Sciences. **Approaches to Source Apportionment-Oyster and Cadmium Workshop.**

Research approaches including geochemistry tools as a potential fingerprint of Cd sources..

14:30-15:00
George Kruzynski, IOS. (see 09:30h).

Comparison of CFIA 2000 and historical data, fate of Cadmium, regulations/consumption/dietary intake comparisons.

15:00-15:30
Carl Alleyne, Health Canada. **Assessment of Risk to Human Health from Contaminants in Foods.**

Risk Assessment protocols, relationship to International sStandards, US FDA, WHO/FAO, CODEX

15:30-15:45 **COFFEE**

15:45-16:00
George Kruzynski, (See 09:30h) **Potential Terrestrial Sources, Introduction**.

16:00-16:15
Kevin Brown, BC Ministry of Forests, Research Branch, Victoria. **Forest Fertilization on Vancouver island as a Potential Terrestrial Source of Cadmium to Oysters.**

Fertilizer application as a potential anthropogenic source of Cadmium to watersheds

16:15-16:45
Ray Lett and Wayne Jackaman, BC Geological Survey. **Cadmium in Coast BC Sediments**

BC mining exploration, coastal geology and potential utility of the (RGS) Regional Geochemical Survey to measure Cd inputs

16:45-17:15
Will Burt and Marcella Snijders, University of Victoria, Department of Geography. **How Satellite Imagery Can Help to Understand Cadmium Contamination in Oysters**

Can remote sensing of watershed disturbance be a useful tool to apply to the terrestrial Cd mobility question ?

17:15-17:45
Pal Bhogal , NRCAN Pacific Forestry Center, Victoria. **Evaluation and Validation of EO-1 for Sustainable Development of National Forests (EVEOSD) - An Overview**
Application of remote sensing technology to mapping watershed coverage, tree physiology, stress and future potential for metals analyses from satellites using hyperspectral sensors.

17:45- 18:15
Gary Borstad, Borstad Associates Ltd., Sidney, BC. **Potential Practical Applications of Remote Sensing for BC Aquaculture.**
Remote sensing as applied to aquaculture impacts, tracking chlorophyll, temperature, suspended sediments, plankton blooms.

*** Useful bits of information**.

Wednesday March 7th
Oceanography and Uptake

08:45-09:15
Sabrina Crispo Earth and Ocean Sciences University of British Columbia. **Marine Geochemistry of Cadmium.**

Information on oceanic Cd pathways, relationships to nutrients eg. phosphate, influence of upwelling and how this cycle may differ in coastal waters. Data on Cd concentrations in BC coastal waters. ~45-75 ng/L however Lares reported up to 278 ng/L during storm events at Amphitrite Point, BC.

09:15-09:45
Frank Whitney Institute of Ocean Sciences. Sidney, BC. **Nutrient Supply Along the Northeast Pacific Margin.**

An outline of upwelling or changes therein over the last couple of decades. Trends in salinity, nutrients, temperature with emphasis on coastal waters where oyster leases are presently and may be in the future up the west Coast of Vancouver Island including the Queen Charlotte Islands. Implications for productivity re-phytoplankton…higher/lower biomass….species differences that may be important to oyster feeding.

O9:45-10:15
Lucila Lares, Departamento de Ecología
Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico.
Mussels as Indicators of Cd in Upwelling Regimes

Responses of California mussels to upwelling events at Amphitrite Point, Ucluelet, West Coast of Vancouver Island. Temporal difference, evidence of regulation of Cd residues. Some discussion of particulate vs dissolved uptake dynamics. Pertinent information from Baja Mexico where apparently there is also some concern about Cd in cultured oysters. Some discussion of differences intra and interspecies Cd dynamics. Ideas why this might be so. Feeding , uptake, binding and depuration differences.

10:15-10:45
Leah Bendell-Young Biological Sciences Simon Fraser University, Burnaby BC.
Cadmium and Oysters

Laboratory and field experiments in uptake dynamics by filter feeding bivalves. Why are oysters different then mussels and clams as far as retention of residues. Why is depuration not feasible. What are the influences if temperature, salinity, geochemistry of Cd, types and sizes of particles filtered, rejected, organic/inorganic, colloidal what is adsorbed, absorbed, differences in plankton uptake of Cd, what determines what is filtered or rejected in pseudofeces. How this changes seasonally, how it is affected by nutrient and food availability. How does uptake in an oyster feeding 24h/day compare with an intertidal one. Are there any physiological or metabolic differences that we know about ?

10:45-11:00 COFFEE

11:00-11:30
Guri Roesijadi Dept. Biological Sciences Florida Atlantic University, Boca Raton Florida, USA. **Mechanisms of Cadmium Sequestration in Oysters**

How bivalves deal with Cd after it is taken up. Effects of salinity and other factors on uptake, metal binding by metallothionein..what it is, why binding is tight and therefore Cd difficult to displace by simple depuration. What is the relationship to zinc, what would happen if zinc were limiting. Are there significant inter and intraspecies biochemical differences if not, why is Cd taken up to higher levels in some and not other bivalve species. Scallops>oysters>mussels>clams. Limitations of laboratory experiments, utility of field transplants. Can these tell us sources or just that one location is better or worse than another? Can this be extrapolated over time or too variable? Feasibility of experimental biochemical mitigation by dietary zinc replacement.

11:30-12:00 Keith Hunter, Russel D. Frew, and Barrie M. Peake. Centre for Chemical and Physical Oceanography, Department of Chemistry, University of Otago, NZ.
Cadmium in Dredge Oysters (*Tiostrea chilensis*) and Related Species in New Zealand Coastal Waters.

Keith had to cancel but did provide an extended Abstract which includes images that would have comprised his presentation. Oceanographic factors resulting in extremely high levels of Cd far from any anthropogenic inputs. Implication of phytoplankton as an important pathway. Possibility of substitution of Cd for Zn

11:30-12:00
Dario J. Stucchi, IOS **Physical Oceanography of Effingham Inlet**

Bottom features, sills, seasonal circulation patterns, temperature/salinity vertical profiles, fresh water lens, horizontal gradients in this watershed of very high rainfall. Sediment geochemistry: are there anoxic zones if so where, could this be a sequestration mechanism for Cd. If so, could Cd be released again with turnover or intrusion of more oxygenated water? One oyster culture site in Effingham had 4.65 µg/g Cd (see Carswell slide # 22; all were > 2 µg/g)

LUNCH 12:15-13:00

13:00-13:30
Robie W. Macdonald, IOS. The General Oceanography of BC's Coast and the Strait of Georgia as it Pertains to Cd Enrichment in Oysters.

Seasonal movement of Fraser River plume, depositional zones, how much might move up the eastern Mainland coastline, would it reach Jervis Inlet, direction of flow. Utility or

lack thereof of core sampling for tracing temporal changes in Cd. How far might very fine particulates, silt, clay, colloidal form of Cd move seasonally. There is a major input of Cd in Vancouver area stormwater..do we know where most of this goes? What is the nearshore seasonal salinity profile heading up the eastern shore of the Strait. Could lowered salinities by facilitating Cd uptake by oysters?

13:30-14:00
Dario Stucchi, IOS. Some Comments on the General Oceanography of the Northern Strait of Georgia and Inlets.

General oceanography of mid to northern part of Strait of Georgia. Contribution of inlets, inlet oceanography, seasonal circulation patterns, temperature regimes, what is it about Bute, Jervis and Toba (Desolation Sound and Redonda Islands that renders these prime oyster growing areas? nutrients, warm temperatures? If so why so, is circulation/exchange reduced by sills, are certain areas protected from winds eg Pendrell Sound? If Cd were added from terrestrial sources, are there reasons why it may become more available to cultured oysters? Are there known anoxic zones(eg. Teakerne Arm) are these near oyster growing areas. How much water comes down seasonally through the Johnstone Strait to the area around Quadra Island? How does this water mass differ from that feeding up from the southern Strait. Does it carry with it SE Alaskan water? Are these inlets characterized by lower surface salinities, if so for how many months of the year? Does this surface input spread across the Strait to Denman Island?

14:00-14:30
Peter Thompson, University of Tasmania: **Cadmium in Pacific Oysters**

Ideas on trophic transfer of Cd via phytoplankton. Could nutrient dynamics be such that might stimulate blooms of species that could be more efficient at sequestering Cd from seawater and on to oysters? What happens if a bloom reduces Zn sufficiently, would preferential uptake of Cd then occur? Recent information that Cd can be utilized by phytoplankton in enzyme function. Any pertinent information from Tasmania? Do we have any local evidence that oysters grown in high density can deplete nutrients and switch to inorganic or organic particulates as an energy source. D.B. Quayle (Pacific Oyster Culture in British Columbia) indicates that a raft of 10 m x 6 m containing 60-100K oysters deposits 0.6-1.0 tonnes of feces and pseudofeces per year. Could this be a mechanism at magnification whether by ingestion at the time or resuspension from the bottom by turbulence at certain times of year?

14:45-15:00 COFFEE

15:00-15:30 DISCUSSIONS

Growers /BC Fisheries *So what do you think? Additional input and discussion. Any local knowledge/conditions that might be pertinent to the information presented above? What else do we need to know?*

15:30- 16:00
Bill Heath BC MAFF: *Planned grow-out experiment. Oysters and mussels. Any modifications based on information exchanged above?*
16:00-16:30 General Discussion

Dinner at Dunsmuir Lodge

19:00> Think Tank/Synthesis Session at Dunsmuir Lodge.

ABSTRACTS

In order presented:

Kruzynski, George, M. *Fisheries and Oceans Canada, Marine Environment and Habitat Science Division, Institute of Ocean Sciences, Sidney. BC.*

Cadmium in BC cultured oysters: An overview

In response to a May, 2000 request by the Canadian Food Inspection Agency (CFIA) the Department of Fisheries and Oceans (DFO), Pacific Region undertook to investigate the potential reasons for apparently elevated Cadmium levels in BC cultured Pacific oysters *Crassostrea gigas*. Earlier in the year, CFIA reported that several shipments of BC farmed oysters had been rejected by the Hong Kong Food and Environmental Hygiene Department as being in excess of their 2 μg Cd/g (ppm) wet weight limit. A preliminary literature search was conducted, contacts were made with shellfish growers and processors, both government and academic researchers were consulted and the resulting information was synthesized by GMK in the form of a PSARC (Pacific Scientific Advice Review Committee) report (http://www.pac.dfo-mpo.gc.ca/sci/psarc/ResDocs/Habitat_00.htm)

We found that there are no historical baseline data on Cd residues in BC cultured oysters, so Cd residue data on wild intertidal oysters collected over the period 1973-1999 by Environment Canada and DFO were used as a comparison. These were mapped and overlaid on current CFIA 2000 oyster data and indicated that in the northern reaches of the Strait of Georgia, there were already Cd residues approaching 2 ppm 27 years ago. In the absence of any obvious anthropogenic Cd inputs, it is suggested that Cd is naturally available in some surface waters where oysters are reared, whether from mineral deposits local geology or sediment transport from watersheds or the heads of fjords. The bioavailability of dissolved Cd may be enhanced by low salinities. On the West Coast of Vancouver Island, Cd accompanying nutrients such as phosphate upwelling from deep waters, could also be a contributing factor.

Among recommendations of the PSARC report was the holding of a Cadmium and Oysters Workshop to exchange information with oceanographers, geologists, geochemists, oyster growers, toxicologists, biochemists and biologists; the objective being to define fruitful avenues of research and possible mitigative strategies.

This paper presents an outline of some of the PSARC information and BC cultured oyster Cd residues are discussed in context of internationally accepted weekly allowable intake levels. The results of a culture materials Cd leaching experiment are also presented.

Maps showing the relationship of BC coastal geology and existing stream sediment Cd data to oyster growing areas are presented and the suggestion is made that BC Fisheries may wish to consider local geochemistry in future oyster lease suitability approvals.

Several hypotheses on Cd pathways from both marine and terrestrial sources as well as potential applications to the BC situation are suggested. This overview is meant to set the stage for subsequent presentations by the 29 invited specialists who elaborate on these ideas.

References

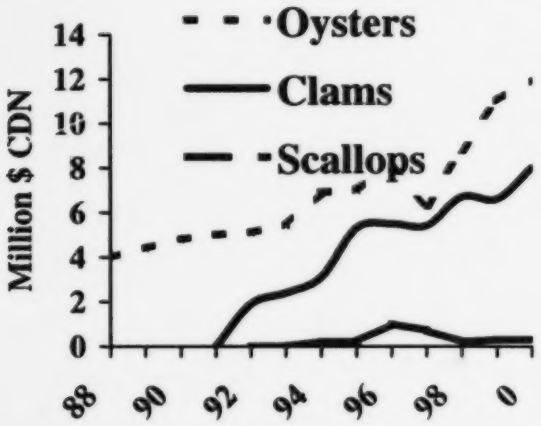
Nelson, H., and D. Goyette. 1976. Heavy metal contamination in shellfish with emphasis on zinc contamination of the Pacific oyster Crassostrea gigas. Environment Canada, Environmental Protection Service, Pacific Region Report EPS-5-PR-76-2. 57 p

Sprague, J.B. 1986. Toxicity and tissue concentrations of lead, zinc and cadmium for marine molluscs and crustaceans. Report prepared for the International Lead Zinc Research Organization Inc., North Carolina, USA. 215 p

Kingzett, Brian. *Kingzett Professional Services Ltd., Duncan, BC*

The shellfish culture industry in British Columbia

Currently the B.C. shellfish culture industry is located in the south coast region that is from the northern tip of Vancouver Island South, in the Strait of Georgia and the West Coast of the Island. The three main species of shellfish cultured in British Columbia are: Pacific Oysters, Manila Clams and Japanese or Pacific Scallops. Of note is that all three species are exotics introduced intentionally or unintentionally from Japan. Also being investigated or developed for culture are blue mussels, geoduck clams and abalone. Current wholesale value of the industry is approximately 20 million dollars.



The Pacific Oyster was introduced from Japan into the Pacific Northwest beginning about the turn of the century and continued up until the Second World War. The Pacific Oyster is barely established in BC with only three small areas where it breeds with any regularity.

The Manila clam was accidentally introduced into British Columbia in the mid 1930s with oyster seed from Japan, it is now established in BC where it has been the subject of a large boom and now almost bust fishery.

The Japanese Weathervane Scallop also marketed as a Pacific Scallop was introduced into BC from Japan by a joint program of the Department of Fisheries and Oceans and the Provincial Government during the 1980s. Broodstock were held in quarantine, bred and successive offspring were used to begin a scallop culture industry in BC.

Shellfish Growers rely primarily on hatchery-produced seed for all three species, clam growers also rely on increasing survival of clam larvae that settle out on culture beds. Of note is that almost all oyster and clam seed is imported from the US.

A very short overview of the main production methods for each species is provided.

OYSTER PRODUCTION

In B.C., generally, oysters are grown for two product forms "shuckers" where oysters are produced for the meats which are shucked in federally inspected processing plants and sold by the volume (typically quarts or gallons). Shucking oysters are usually between 4 and 6 inches and usually shuck out at 100-120 per US gallon. Growers are paid on how their product shucks out and usually receive between 15 and 17 dollars per gallon. Current production is about 100,000 gallons annually.

Oysters are also produced for the single or half shell market. Single oysters are sold "in shell." This product is of higher value and is sold by the dozen in a variety of size grades ranging from 2 inches to greater than 6 inches. Farm gate prices range from about $1.75 to more than $6.00 per dozen. Recently there has been a significant amount of production going to flash-frozen as meats, whole oysters or TVO, which is top valve off.

BC Growers are a diverse lot and there are a variety of methods used for growing out oysters depending on the site, the type of product and the method preferred by the grower:

Seed is acquired as larvae, and it is remote set on site or a central site, onto substrate usually old oyster shells or it is acquired as singles and may be nursed up in Floating upwellers (FLUPSY) to approximately 1 inch.

The oldest and simplest grow-out method is to spread oysters out on the beach and wait for them to grow. Grow-out times for beach product range from two to five years.

Beach Oysters

- Hard shells do not break
- Harder to shuck
- Longer shelf life –more marketable
- Slow growing
- Less fluting little colour

Much of the development of the industry is coming from deep-water or off-bottom culture where oysters remain fully submerged. Grow-out time is usually halved and 4-5 inch oysters large enough for shucking product can be produced in two growing seasons in most areas. Oysters are never grown out on the bottom in deep water.

Deepwater Oysters

- Soft shells often break
- Easier to shuck
- Shorter shelf life –less marketable
- Fast growing

The most common techniques include: mother shell inserted into specially made two strand poly rope (string culture), or with oysters attached to artificial cultch known as "French pipes" (tube culture), which are individually hung vertically from longlines for 2 year grow-out to 4-6 inches.

String Culture –Oyster seed on shell inserted into two-strand rope

- Lower money up-front
- Higher labour costs
- Hard to mechanise harvest

Tube (Pipe) Culture –Oysters attached to PVC tubes

- Higher money up front
- Less Labour
  - Can be mechanically harvested

Or as single oysters contained in plastic culture trays, grown for about one to two years and then placed into the intertidal to harden the shellstock or sold directly.

Two main types of trays are used:

Dark Sea Trays

–Shallow trays 10-15 per stack
–Grow 3/4" seed - X-small/small

High Flow Aqua-tech Trays

–Deep trays in stacks of 7
–Grow small and medium oysters

Aspects of Deep water tray grown oysters include:

- Grow-out times 12-18 months
- Better meat quality
- Softer shells less marketable may require hardening
- Higher labour costs/more equipment

Whatever the method, farmers working deep-water leases may use longlines or rafts to suspend the oysters being cultured.

Characteristics of Longlines are:

- Best for large, more exposed or sites with less current
- Use with trays, pipes or strings
- Surface or subsurface longlines
  Barrels or oyster floats

Rafts made from wood and styrofoam floatation are used to produce Large amounts of production in a small area.

- Best for small or sites with sufficient current
- Use with trays, pipes or strings
- Two and three foam designs

MANILA CLAMS

Clam farming is a relatively new venture in British Columbia. The first permitted clam farms in B.C. were established on existing shellfish culture leases in 1988, and the licensing of clam farming did not become official until 1991.

Hatchery produced clam "seed" are purchased from nurseries in B.C., Washington or California. This seed is spread directly out onto firm, low sloping mud-gravel grow-out beaches.

To protect the significant investment in seed from scoter ducks, flounder and crab all of which consider young clams as prize food, panels of a light-weight plastic net is laid down across grow-out plots and secured. Mature clams are harvested by hand digging after two to three years of grow-out.

Scallop culture

he scallop industry is still in its infancy in British Columbia as growers overcome a variety of production hurdles but it is anticipated that production of this species will increase dramatically in the very near future. Production is hatchery based and with one hatchery in BC producing scallop juveniles. The species is fast growing with marketable product able to be produced within two years of the hatchery.

GMK Note: for additional detail including photographs and diagrams consult:
http://www.island.net/~bcsga/bcsgirs/main/sgmain.htm

Dewey, William F. *Taylor Shellfish Company, Inc. Shelton, Washington*

Cadmium in Taylor Shellfish Company oysters, Washington, USA

the fall of 1993 and spring of 1994 Taylor Shellfish had elemental analysis performed on samples of oysters from Samish Bay in Northern Puget Sound and Totten Inlet and Pickering Passage in Southern Puget Sound. Cadmium was one of the elements quantified in the analysis.

Taylor Shellfish Company has export markets which include Hong Kong. Taylor Fine Foods, Ltd is a distributorship whichTaylor has established in Hong Kong. Because of this vested interest in the Hong Kong market and Taylor's sampling being some of the only data available on Cadmium in Washington's oysters, Mr. Dewey agreed to participate in DFO's Institute of Ocean Sciences March 6, 2001 workshop on Cadmium.

The initial sampling was undertaken at the request of Dr. Susan Cook, a research scientist who lived in the agricultural area adjacent to Samish Bay. Dr. Cook was hypersensitive to heavy metal contaminants and was aware of elevated levels of arsenic in the region. Dr. Cook was aware of high levels of arsenic and cadmium being present naturally as a result of local geology. Dr. Cook also suspected fertilizers applied by an extensive agricultural industry in the watershed could be a source. She was interested in the oysters potential ability to bioaccumulate these contaminants.

In December 1993 oyster samples were collected from Samish Bay (Northern Puget Sound) and Totten Inlet (Southern Puget Sound) and shipped to Elemental Research in Vancouver B.C. for processing. In April 1994 additional oyster samples as well as bottom substrate were sent from Samish Bay intertidal longlines and oysters from Pickering Pass (southern Puget Sound control) in an effort to explain dramatic growth rate variation between oysters on the bottom and those suspended in ropes 40 cm above the bottom.

It was not known whether Elemental Research in Vancouver followed the same testing protocols as DFO, whether pallial fluid was included or even whether the oysters were shucked prior to processing the samples. The samples were believed to have been a composite of multiple oysters. Of the five oyster samples run, Cadmium levels ranged from 0.65 μg/g to 2.09 μg/g (wet weight).

The Cadmium levels found were well below the U.S. Food and Drug Administrations recommended level of 3.7 μg/g and thus did not represent a concern for the company. Periodic sampling by Hong Kong has not apparently detected levels over their 2.0 μg/g acceptable limit since none of Taylor's shipments have been rejected.

Heath, William A. *Shellfish Production Specialist, BC Ministry of Agriculture, Food and Fisheries, Courtenay, BC.*

Site selection considerations for shellfish farming in British Columbia.

BC Fisheries, part of the Ministry of Agriculture, Food and Fisheries, has the mandate to lead the provincial government's efforts to build and sustain healthy fish populations and to develop and diversify the fisheries and aquaculture sectors.

Diversification of the shellfish farming sector will involve producing new products by innovative methods in new locations along the BC coast. The selection of appropriate sites for the farming of shellfish is central to the economic viability of new or expanding shellfish operations. Factors to consider include biophysical attributes (physical and biological conditions) and suitability issues (e.g. risk of conflict with other incompatible resource uses). A convenient way of combining these criteria is through use of a "Site Capability Index" or SCI, with numerical values between 0 (worst) and 1 (ideal), similar to the widely used habitat suitability index approach. Nearly all of the British Columbia coast has been assessed for shellfish capability for culture of the Pacific oyster (*Crassostrea gigas)*, the Manila clam *(Tapes philippinarum)*, and the Japanese scallop *(Patinopecten yessoensis).*

In addition, socio-economic factors such as the availability of infrastructure, labour and marketing resources will also affect the viability of operations. In the context of low ($\leq$2 ppm wet wt.) current or proposed Cd threshold levels for export markets and relatively high natural Cd concentrations in BC waters, it is also prudent for shellfish agencies and farmers to better understand the process of Cd accumulation in commercial shellfish in the various growing regions of British Columbia. There is a distinct possibility that shellfish Cd levels may become an important suitability factor for shellfish site selection.

Carswell, B. 2001. *Economic Development Officer, A/Manager Resource and Community Planning Unit, Sustainable Economic Development Branch BC Fisheries, Victoria, BC.*

The BC Shellfish Development Initiative process and the relevance of cadmium concentration data in BC cultured oysters to industry development

The Provincial Shellfish Development Initiative announced in November 1998 has as its goal doubling the amount of area under tenure for shellfish aquaculture from 2115 ha to 4230 ha. With this increase in cultivation area, the industry has the potential to increase wholesale values from 13 M to 100 million, and provide 1000 new person years employment in coastal communities. Development of the industry is preceded by consultation with First Nations, other government agencies, communities and industry. The model used for the consultation involves the formation of Regional Shellfish Steering committees, which consist of a wide spectrum of coastal stakeholders. These

committees provide advice to government on how best to proceed with shellfish development initiative in local communities. Specific work of the committees includes;

1) Development of shellfish suitability maps showing areas that the community deems that shellfish aquaculture is/is not an appropriate use;
2) Indication of industry growth rate that community deem acceptable/desirable;
3) Developing criteria that could be used to rank competing applications, when industry growth rate above would be exceeded (if all applications received were accepted and approved) or when applications overlap;
4) Ranking the applications when necessary under 3, and provide government with advice on the applications deemed most desirable from a community perspective. (Undertaken as necessary upon receipt of applications).

Steering Committees have been set up for Powell River, Barkley Sound, Clayoquot Sound, Nootka -Kyuquot Sound, Quatsino Sound, Comox Valley, and the North Coast.

By digitising the suitability analysis from the committees and combining with digital capability data we are able to determine the areas of greatest opportunities. As shown, additional data sets such as existing commitment on Crown land, bathymetry and the results of Cadmium sampling can further assist in site selection.

Dobie, Sheila *Seafood Development Office, Skeena Queen Charlotte Regional District Prince Rupert B.C.*

Notes on the North Coast Shellfish Industry, April 2001

The north coast is an important location for any further investigations of cadmium levels in shellfish. Current local investments towards developing new shellfish farming industries make baseline water quality assessments critical. The existing farms on Porcher Island and in Skidegate Inlet have been participating in the biotoxin program and in other piloting initiatives. In addition, First Nations communities have been directly participating in a community based biotoxin monitoring system that gives any additional investigations a structure and coordinating base, as well as links to Northwest Community College and Northern Labs.

Salmon, Ruth. *Executive Director, BC Shellfish Growers Association, Duncan, BC.*

How Industry sees the Cadmium issue

Brief Profile of Shellfish Aquaculture In BC
Small, growing industry (approximately 12 million farmgate in 1999)
250 companies; 400 culture sites
Shellfish Farmed:

- Pacific Oysters

- Manila Clams
- Pacific Scallops
- Mussels & Geoduck

Who is the BCSGA?
The B.C. Shellfish Growers Association (BCSGA) is the voice of the shellfish farming industry in BC and has been in existence since 1948.

In the last few years, the BCSGA has been steadily increasing its membership that currently stands at approximately 150 members. The association represents the majority of shellfish growers in BC and over 85% of the farmed shellfish production.

Cadmium – the issue
The issue of Cadmium in oysters is not confined to Canada as is demonstrated today by the presence of workshop participants from Australia, New Zealand and Mexico. However, we are pleased that Canada is taking a leading role in assessing the issue & initiating a forum for the exchange of information. Our association is also pleased to be a part of that discussion –because of course, it is a priority of our industry to continue to market safe product.

The importance of food safety is reflected in the program initiatives of our association. In addition to the development of an industry Environmental Management System, food safety and quality assurance programs take up a large percentage of both Board and staff resources. To give you some examples…

1. The SGA, together with CFIA & provincial health authorities, is an active participant on the provincial *Vibrio parahaemolyticus* committee. To assist growers supply a safe product during the summer months when the risk of elevated Vp levels are higher, the BCSGA helped to develop harvesting guidelines for growers. Following this, we provided all growers with a harvesting kit, which included a pocket thermometer for determining accurate meat temperatures and a Bill of Lading for tracking key harvest information.

Every effort was made on the part of industry to help reduce the risk of illness & the combined efforts of producers & processors resulted in almost negligible illnesses last summer.

2. We are also currently participating in a national program to develop a farm based HACCP system for improved quality assurance at the farm level. This program involves a series of pilot projects to test and incorporate HACCP methodologies and techniques for grower involvement in water quality monitoring programs. The use of a HACCP framework will provide a mechanism for grower participation and funding, micromanagement of growing areas and increased quality assurance *without* compromising the roles of federal regulatory agencies or the Canadian Shellfish Sanitation Program. The project will also assess the cost-benefit and technical issues surrounding the use of site-specific classification of growing waters.

I've shared these examples only to illustrate the kind of emphasis our association puts on the issues of food safety and quality assurance. The same philosophy also applies to Cadmium. Industry views continued research into the Cadmium issue positively. However, the only caution we would bring forward is that since all issues of food safety are both complex and sensitive, they must be handled extremely carefully in the public arena.

Clearly the issue of Cadmium is receiving heightened interest internationally. Cadmium in ALL foods is undergoing a review in the Codex Alimentarius, but any decision by this body is not expected in the near future. While we all collectively research the issue & continue to explore ways of reducing naturally occurring cadmium levels in shellfish, we must remember the current facts:

- All evidence to date suggests that Cadmium is a naturally occurring phenomenon unrelated to pollution and occurs in all areas of the oceans with high mineralization.
- Our industry is highly regulated and rigorous government controls are in place to assure the safety of oysters for consumption.
- Canadian oysters fully comply with existing international standards and those of its major markets, particularly it's most important market, the US.

Webb, Allison. *West Coast Advisor, Office of the Commissioner for Aquaculture Development, DFO*

Shellfish Monitoring Project

Budget reductions in the federal government have resulted in declines in services for water quality and marine biotoxin testing for the shellfish aquaculture industry in British Columbia. This was of concern for current growers as well as prospective entrants to the sector. This same situation was expected in other areas of Canada as well. As a result of a proactive approach to this situation, the shellfish industry approached the Office of the Commissioner for Aquaculture Development and garnered support for the development of a national Shellfish Monitoring Project which aims to increase industry participation in water quality and marine biotoxin monitoring programs

This project has the support and participation of all 3 departments/agencies that administer the Canadian Shellfish Sanitation Program (CSSP), Environment Canada, the Canadian Food Inspection Agency and Fisheries and Oceans. As well, there is representation from the shellfish industry from across Canada.

The main initiatives of the project are: the development of a farm based quality assurance program in the form of the well accepted Hazard Analysis Critical Control Point (HACCP) program; the commercial species project which aims to test the use of commercial species as sentinel species as opposed to the California mussel with the

expectation that uptake and depuration levels/rates will be different and may allow a longer growing season; and a communications initiative to foster better information two way information flow between industry and government regulators. Information on heavy metals and contaminants are being discussed within the parameters of this study.

The project began in the Spring of 1999 and is expected to be completed in the Winter of 2001. Recommendations on possible changes to the delivery of the CSSP will be forthcoming at that time

Liem, Sing. *Chief, Fish Program Network, Western Area, Canadian Food Inspection Agency, Burnaby, B.C.*

CFIA's Role in Food Safety Mandate

The Federal Government's Food Safety Mandate is delivered through a shared responsibility between Health Canada and the Canadian Food Inspection Agency (CFIA).

Health Canada, who has the food safety mandate for Canadian consumers, develops food safety policies, set standards, conduct risk assessments and audit the delivery of the Food Safety Programs. The Canadian Food Inspection Agency is responsible for the delivery and enforcement of the Food Safety Mandate and enforces all federal legislation on food inspection, agricultural inputs, animal health and plant protection.

The Fish, Seafood and Production Division within CFIA is responsible for the delivery of an inspection program to provide reasonable assurances that fish are safe, wholesome, of acceptable quality and are fairly traded. The Fish Inspection Act and Regulations provides the regulatory framework for controlling all aspect of preparing fish for market, including the transportation, unloading, handling, processing, labelling and certification of fish products.

The Canadian Shellfish Sanitation Program provides the policies and controls for the safety of molluscan shellfish. As part of this program, CFIA monitors product for marine toxin, pathogens and contaminants, including Cadmium.

Schallie, Klaus. *Aquaculture & Molluscan Shellfish Specialist, Canadian Food Inspection Agency, Burnaby, B. C.*

Results of the 2000 Survey of Cadmium in B.C. Oysters.

In 2000 the Canadian Food Inspection Agency embarked on a survey of cadmium levels in the major oyster growing areas of British Columbia. This was in response to information from the Hong Kong Food and Environmental Hygiene Department that several shipments of oysters from British Columbia were

found to have cadmium levels that exceeded their action level of 2 ppm (wet weight).

CFIA staff began by reviewing historical data from the CFIA's own Environmental Contaminants Program. It was noted that Cadmium levels in approx. 39% of the samples of oysters and scallops exceeded 2ppm but that levels were < 2 ppm in other species of shellfish, marine invertebrates and finfish. Environment Canada also provided some analysis results from their monitoring surveys and these cadmium levels were consistent with the CFIA's data following conversion from dry weight.

Oysters for our survey represented all of the major growing areas and also different sizes and culture methods. More than 60% of our samples taken in 2000 had levels of cadmium over 2 ppm and the mean for 81 samples was 2.63 ppm. All of the major volume growing areas were found to have means over 2 ppm. Only two areas show results that are consistently under 2 ppm. These are the southern portions of DFO Statistical Areas 17 (southeast Vancouver Island near Ladysmith) and 24 (southern Clayoquot Sound.)

No relationship between size/age of oysters and cadmium levels was apparent, likewise for intertidal vs off bottom (long line or tray) culture. Consequently, no shipments of oysters from B. C. are being certified for the Hong Kong market at this time.

Regulatory limits for cadmium in shellfish vary widely from country to country and there is currently a review being conducted by the WHO/FAO. The data from the 2000 cadmium survey was forwarded to Health Canada with a request for an updated risk assessment. Also, CFIA is reviewing the data to identify other samples which could be taken to fill gaps in our knowledge.

Knapp, Wayne. *Fisheries and Oceans Canada, Habitat and Enhancement Branch, RHQ, Vancouver, BC.*

Cadmium in Shellfish: Habitat Management Roles and Responsibilities

There are three general aspects to the cadmium in shellfish issue: problem identification (i.e. scope and significance), human health implications of consuming cadmium contaminated shellfish and potential need for restrictions on harvesting of seafood products. The Department of Fisheries and Oceans (DFO), Habitat and Enhancement Branch (HEB) is concerned about cadmium contaminated shellfish in light of the Department's responsibilities for fish and fish habitat protection, because the contamination could affect both wild and culture shellfish species and because of the broad responsibilities for ensuring product quality in the commercial, recreational and 1st Nations harvesting of these resources.

HEB supports DFO Science staff in the scientific assessment of the issue, provides supporting information (e.g. resource distribution and harvesting information) and may assist in the collection and analysis of samples. The Branch co-ordinates information to and Regional DFO requests to health agencies (e.g. Health Canada) for health hazard assessments.

Based upon the advice of health agencies HEB, in consultation with other agencies and user groups as appropriate, determines the need for, and extent of, fish harvest restrictions with an emphasis on the commercial, recreational and 1st Nations fisheries. These actions may be taken pursuant to the *Management of Contaminated Fisheries Regulations* or the *General Fisheries Regulations* (Variation Order). Where contaminants originate from anthropogenic sources HEB may, in conjunction with Environment Canada, investigate contaminant reduction pursuant to Section 36(3) of the *Fisheries Act* (prohibition of the discharge of deleterious substances).

Telmer, Kevin. *School of Earth and Ocean Sciences, University of Victoria, Victoria, BC.*

Approaches to Source Apportionment - Oyster and Cadmium Workshop, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia.

The source of Cadmium (Cd) found in Canadian West Coast oysters is currently unknown. The use of stable and radiogenic isotopes and major and trace elements to fingerprint the source of chemicals to naturally occurring processes or anthropogenic impacts – methods of "source apportionment" – may be a fruitful approach to improving our understanding of the source of Cd in oysters. It can broadly be accomplished in 5 ways:

1. Chemical Fingerprinting – "Environmental Forensic Science". This can accomplished by identifying a chemical constituent unique to a plausible source of that constituent. In the case of synthetic chemicals such a PCBs, the source is unquestionably unatural and the precise structure of the compound may be unique to a manufacturing process or distributor and so can be readily identified. Chemical fingerprinting can be more difficult for naturally occurring materials such as metals. In this case, the most reliable link to source are unique isotope ratios. The power of this approach has recently been illustrated for sources of Pb in the southern hemisphere by Bollhofer and Rosman (2000; Geochim. Cosmochim. Acta. Vol. 64). They are able to uniquely isolate multiple sources of Pb by measuring 206/207 and 208/207 ratios. Elemental associations (does elevated Pb occur along with elevated levels of other substances) also represent a method of chemically fingerprinting source but for natural materials, only isotopic ratios can provide indisputable evidence of the source of elements – the so called "smoking gun."

2. Spatial Analysis – anomalies in space and their associations. Statistically, or qualitatively correlating elevated metal concentrations with landscape features such as geology, water type, plankton, forestry, landuse, industry, agriculture, urbanity and point sources has been a "pathfinding" strategy employed by scientists for many years. This approach is often informative and can greatly assist in formulating ideas and testing hypothesis but rarely provides irrefutable evidence for source. The robustness of this approach, however, is improving with innovations in remote sensing making many more spatial data products available. Combining this approach with the others described here also offers the potential for greater insight.

3. Temporal Evidence – comparing past to present. By observing enrichments or depletions in elements in a single media through time – in ice cores or sediments – inferences can be made about recent rates of environmental dispersal versus historical rates. This approach works well if the media used to extract the historical record is relatively inert both chemically and structurally. Unfortunately these criteria rarely occur in nature – with ice cores perhaps representing close to ideal behaviour. The ability to extracting an irrefutable historical record of element deposition from subaqueous sediments is however hotly debated. It may be possible by carefully choosing a location and analysing the right material but it is no easy task and so this approach is also rarely attains irrefutable source apportionment evidence.

4. Speciation / Partitioning - Which phase? Solid, aqueous, gaseous? Crystalline or amorphous? Mineralogical or adsorbed? The "chemical location" of elements in the environment tells us much about pathways and bioavailability and also provides information about source. For example the Pb contained in highly resistant silicate minerals in sediment cores is unlikely of anthropogenic origin and is unlikely a source of toxicity whereas the Pb bound to amorphous iron oxyhydroxide coatings on mineral grains could be. The distribution of elements in the sample matrix therefore is useful information in constraining source (as well as behaviour) but rarely provides the "smoking gun" for source.

5. Mass Balances – Mass distribution and at what flux rate? The mass of an element that passes through or is contained within a system is often a strong constraint on source apportionment hypotheses. For example, an up-core enrichment of Hg in lake sediment cores may seem to provide evidence of a recent increase in Hg deposition due to anthropogenic emissions (perhaps from coal burning). However when coupled with direct measurements of Hg deposition to the lake system, the mass of Hg bound in the uppermost layers is simply too high to be explained by atmospheric deposition. In such a case, new hypotheses invoking other fluxes must be formed to explain the mass distribution in the environment.

Only the first and last methods, isotopic evidence and mass balances, offer irrefutable evidence about source. The others provide useful information for constraining ideas about source but rarely are able to quantitatively apportion it. With this in mind, Cd isotope systematics are being investigated as a possible source apportionment tool for Cd in oysters. Currently, six samples have been submitted to Micromass, UK, for

determination of the eight naturally occurring Cd isotopes. The samples are two sequential extractions (weakly bound / strongly bound) of lake sediments from three depths. The results of these analysis may provide a starting point for applying isotopic evidence to sources of Cd.

Alleyne, Carl. *Health Products and Food Branch, Health Canada, Burnaby, BC.*

Assessment of Risk to Human Health from Contaminants in Foods

Health Canada shares its responsibility for a safe food supply with other partners, including the Canadian Food Inspection Agency (CFIA), and other levels of government, *viz.*, Provincial, Territorial, and Municipal. The specific activities which it undertakes on foods, include policy development, standard-setting, risk/benefit assessments, research, pre-market reviews, and surveillance of the food supply.

The health risks from consumption of foods containing toxic contaminants entails are assessed by comparing the probable daily dietary intake (PDI) of the contaminant with the tolerable daily intake (TDI). PDI depends on the amount of the food consumed and the contaminant level, while the TDI is based on the inherent toxicity of the contaminant and also includes a safety factor. For example, the provisional TDI recommended by the World Health Organization and the Food and Agriculture Organization (WHO/FAO) for cadmium is 7 micrograms per kilogram body-weight per week. The WHO/FAO TDI is not universally accepted since some countries set their own guidelines. Health Canada has not set a national guideline for maximum contamination levels of cadmium in foods. For risk assessment purposes, Canada generally aligns its national food standards with those of the Codex Alimentarius Commission (Codex), an international body which has a mandate to establish and harmonize international food safety standards.

Codex recently proposed a draft standard for maximum levels of cadmium in molluscs and other foods, *viz.*, 1 milligram cadmium per kilogram (mg/kg or parts-per-million) for molluscs. At the time of writing (May 2001), this proposal has not been adopted and is at Stage 4 of an 8-step approval process. The Codex Committee on Food Additives and Contaminants (CCFAC), the body which is responsible for the cadmium standard, is accepting comments from committee member countries for consideration and possible amendment of the proposed standard. As an interim measure, while the draft standard for cadmium in molluscs is being discussed, Health Canada is using the proposed maximum level of 1 mg Cd/kg molluscs for risk assessment purposes.

Brown, Kevin. *British Columbia Ministry of Forests Research Branch, Victoria*

Forest fertilization on Vancouver Island as a potential terrestrial source of cadmium to oysters[1]

Cadmium (Cd) occurs in fertilizers containing phosphates and some trace elements. In coastal forests of B.C., such fertilizers are often applied to individual seedlings at the time of planting. Established stands are generally fertilized only with N, primarily as urea (46-0-0). Aerial fertilization of some young western hemlock stands on northern Vancouver Island with N and P has also been initiated during the past 12 years. While fertilization at planting occurs only once during the lifetime of a stand, established hemlock stands could conceivably be fertilized an additional 1 to 3 times prior to harvest (anticipated at age 80-150). The fertilizers applied at planting, along with the N+P fertilizer applied to some hemlock stands, could conceivably be a terrestrial source of Cd to oysters farmed along the coast of Vancouver Island.

Estimates of Cd loading from forest fertilization are complicated by several factors: (1) data on Cd concentrations are not readily available for the specific fertilizers applied; (2) reported concentrations for a specific formulation vary with the sources of the primary fertilizers and the sampling and analytical procedures used; (3) rates and formulations applied vary over time. For fertilizers applied at planting, the most comprehensive data available are for the Greater Nanaimo watershed (Table 1; www.city.nanaimo.bc.ca/speed/gnwd/src/fertilizer.pdf). From 1998-2000, four fertilizers were applied at the time of planting. Rates ranged from 30-50 g seedling^{-1} and planting densities ranged from 978 – 1150 seedlings ha^{-1}. Cadmium concentrations reported for the Dawson Seed 25-9-9 fertilizer applied in 1998-1999 ranged from 0.5 – 42 μg g^{-1}. This compares with a typical background concentration in soil of 0.35 μg g^{-1}. In total, approximately 0.485 kg Cd was applied via fertilization at planting in the Nanaimo watershed from 1998-2000, equivalent to 0.46 g Cd ha^{-1}.

The young western hemlock stands on northern Vancouver Island which are aerially fertilized with N+P receive 75 kg P ha^{-1}, i.e., ~ 385 kg ha^{-1} of triple super phosphate (0-45-0). Cadmium concentrations in triple super phosphate may be as low as 15 μg g^{-1} (Brown, unpubl. data), but were as high as 115 μg g^{-1} (Washington Dept. of Agriculture; www.wa.gov/agr/pmd/fertilizers/index.htm#database), which would translate to a range of ~ 6 - 44 g Cd ha^{-1} per application. The average area fertilized on northern Vancouver Island from 1989-2001 was 971 ha year^{-1} (range of 0-3416). Approximately 75 % of the area fertilized with N+P drains into Quatsino Sound. Forest fertilization with P could then result in a potential Cd loading of 4 – 32 kg year^{-1} to watersheds draining into Quatsino Sound. A summary of potential Cd loadings from fertilization at planting and from N+P fertilization later in stand development is shown in Table 2.

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[1] The assistance of John McClarnon and Rob Brockley (British Columbia Ministry of Forests Forest Practices and Research Branches, respectively) and Annette van Niejenhuis (Western Forest Products) in preparing this submission is gratefully acknowledged.

Potential loadings of Cd from forest fertilization at planting appear low, compared with loadings from other known sources. Potential loadings of Cd from aerial fertilization are higher, but vary greatly with the concentration of Cd in the applied fertilizer. Over time, Cd loading from fertilization is minimized by the infrequency of applications over the lifespan of a stand. Migration to surface waters of Cd applied in P fertilizers will be further minimized by 10 metre-wide streamside (no fertilization) buffer zones specified in the Forest Fertilization Guidebook (www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/fert/ferttoc.htm), by the adsorption of Cd by soil, and by the uptake and accumulation of Cd in above- and below-ground biomass. However, assessments of the fate of Cd applied in fertilizers are hampered by difficulties in quantifying the amounts added, and by a limited understanding of the behavior of applied Cd in forest soils.

Lett, Ray and Wayne Jackaman, *B.C Geological Survey, Victoria, BC.*

Cadmium in Coast BC Sediments

Elevated cadmium levels have been detected in shellfish tissues at several locations along the British Columbia coast. Among the common geological sources for cadmium are zinc sulphide (sphalerite), secondary zinc minerals (smithsonite) and sedimentary rocks. Rock-forming silicate minerals typically have less than 1 ppm cadmium. Coastal B.C. and Alaska geology represents periodic collision of island arc chains, carried by continental drift across the Paleo-Pacific ocean, with ancestral north America over the past 200 million years. Distinct geological terranes (e.g. Stikina, Wrangellia, Alexandra) were formed by these collisions. Massive lead-zinc-copper sulphide deposits hosted by the volcanic, sedimentary and intrusive rocks forming these terrains are a likely primary source for the cadmium. Weathering of minerals releases cadmium and other metals into streams where they may concentrate in bottom sediment. Ultimately, metals can be discharged into the sea from coastal streams either bound to suspended sediment in stream water or in solution.

Cadmium levels in coastal stream sediment have been determined as part of a regional geochemical survey (RGS) carried out by the British Columbia Ministry of Energy and Mines Geological Survey Branch. These surveys are aimed at stimulating mineral exploration. The < 0.177 mm size fraction of active stream and moss mat sediment, collected at a average density of 1 sample/10 to 13 square kilometers, is routinely analysed for up to 50 elements including cadmium by a combination of instrumental neutron activation (INAA) and aqua regia-atomic absorption spectrometry (AAS). Stream water samples are analysed for uranium, fluoride, sulphate and pH. Since 1977 over 45,000 samples have been collected covering 70 per cent of the province. RGS data has revealed that cadmium levels up to 1.9 ppm occur in sediment from the Bamfield area, 7.5 ppm in sediment from the Cortes Island area and up to 2.2 ppm in streams draining into Jervis Inlet. There is no clear link between the source and the presence of elevated cadmium in sediment or shellfish although there are potentially cadmium-bearing mineral occurrences in the watersheds of some coastal streams.

Burt, Will and Marcella Snijders. *Department of Geography, University of Victoria, Victoria, BC.*

How satellite imagery can help to understand cadmium contamination in oysters.

This presentation introduces the fundamentals of satellite remote sensing and displays Landsat Thematic Mapper 7 (TM) images of some oyster license regions to provide a qualitative review of possible anthropogenic activities on land cover in these regions that may contribute to elevated cadmium concentrations in the oyster population.

Images of Effingham Inlet, Baynes Sound, Desolation Sound and Clayoquot Sound were produced using TM bands five, four, and three that were acquired in 1999. This band combination highlighted differences in vegetative cover in the study areas and thus allowed the identification various stages of forest growth, forest denudation, roads and agricultural land uses.

In all four regions, anthropogenic activities such as logging, road building and agriculture can to be seen to have a dominant effect on the landscape. No obvious visual correlation between oyster sites with elevated cadmium concentrations and land use could be made due to the wide extent of anthropogenic activities throughout all the areas of interest.

To conclude the presentation, another application of remote sensing in relation to the oyster cadmium concentration problem was suggested. This application would use either satellite or airborne remote sensing in conjunction with ground based sampling to detect the mode and extent of cadmium transportation within the suspended load of coastal river plumes.

Bhogal A.S. (Pal) [1], D.G. Goodenough[1,2], A. Dyk[1], R. Hall[3], J. Iisaka[2], D. Leckie[1], A. Hollinger[4], J. Pearlman[5], J. Miller[6], Olaf Niemann[2], Karl Staenz[6], Harold Zwick[7]

[1]*Pacific Forestry Centre, Victoria, B.C.*
[2]*University of Victoria, Victoria, B.C.*
[3]*Northern Foresty Centre, Edmonton, Alberta*
[4]*Canadian Space Agency, St. Hubert, Quebec*
[5]*TRW, Redondo Beach, CA.*
[6]*Canada Centre for Remote Sensing, Ottawa, Ontario*
[7]*MDA, Richmond, B.C.*

Evaluation and validation of EO-1 for sustainable development of National Forests (EVEOSD) - An overview

Hyperspectral sensors provide measurements of targets at high spectral resolution. In the forest, canopy chemistry can be used to estimate new and old foliage, detect damage, identify trees under stress, and map chemical distributions in the forests.

At this time, our hyperspectral work involves a new project entitled "Evaluation and Validation of Earth Observer-1 (EO-1) for Sustainable Development of forests (EVEOSD)". NASA's EO-1 satellite was successfully launched on November 21, 2000. Data collection over the Greater Victoria Watershed District (GVWD) will commence in July 2001. In September 2000, in preparation for airborne and spaceborne data collection and calibration, we collected foliar canopy and ground cover chemistry samples from 54 plots distributed across the GVWD test site. Treetop samples were collected from helicopters, and concentration of both organic and inorganic constituents was determined. One of these inorganic compounds was Cadmium. We are continuing our analysis of organic and inorganic constituents in the foliage in our test site, with further data collection scheduled for the summer of 2001.

In this paper, we provide an overview on the application of hyperspectral sensors to the extraction of forest attribute information, both directly and indirectly. We also discuss the value of multi-temporal and multi-sensor data fusion with GIS for calibrating spectral measurements and validating observations of forest stands under stress.

Borstad, Gary. *G.A. Borstad Associates Ltd, Sidney, BC.*

Potential practical applications of remote sensing for BC Aquaculture

The most practical applications of remote sensing to BC aquaculture currently are:

- upland use (logging, agriculture other land use);
- suspended inorganic sediment concentration, turbidity, water clarity ;
- sea surface temperature;
- phytoplankton chlorophyll concentration, red tide mapping.

All of these parameters can be mapped quantitatively from one or more satellite sensors and from aircraft, but it is important to realize that the more detail one wants, the more it costs, and the less often it is available. Satellite sensors cover large areas repeatedly, but for these parameters are blocked by cloud. Aircraft can carry sensors to make measurements under cloud of smaller areas and provide the platform to make visual observations, and to take in situ samples.

There is a "family" of satellite sensors aimed at global coverage that provides free or low cost data at about 1 km spatial resolution, and nearly daily coverage. A series of American weather satellites operating at these scales provides sea surface temperature imagery. Water colour sensors from several countries are now providing semi-quantitative imagery of phytoplankton blooms. Although more work is required to improve the accuracy of their measurements, these sensors provide useful description

of large blooms and upwellings on the outer coast, but will be of limited use in inlets or near the coast.

At present, the area very near the coast and in fjords can be imaged with several sensors having spatial resolution in the range 15 to 30 m. However these sensors generally have fewer spectral bands [they are capable of only crude colour measurements] and have long repeat cycles [they only return over a particular site about every two weeks]. Because they image any particular area less, the chances of imaging on cloud-free days is less. Generally these sensors are commercial and there is a charge for the data.

Later this year, the European Space Agency (ESA) will launch MERIS, a sensor with 300 m resolution designed for detailed quantitative water colour measurements in the coastal zone. It should be capable of quantifying pigment content in plankton blooms even into the fjords, as well as perhaps monitoring the physiology of the blooms.

Suggestions:

1. Use the UVic Landsat Archive (of which Jim Gower has a copy) to make 'snapshot' images of relative sediment concentration [as % Reflectance] and Surface Temperature in BC inlets. (30 m resolution).
2. Use Landsat Archive to map land-use above present and past aquaculture sites. (30 m).
3. Use ASTER data freely available on-line to map land use (15 m resolution), and water temperature - (infrequently).
4. Use Coastal Zone Colour Scanner (CZCS) archive (1978-1986: recently assembled by Borstad for Parks Canada) to study seasonal and inter-annual changes of phytoplankton on the coast (this has only begun and there is no funding to continue).
5. Use SeaWiFS archive (1997 – present) created by Jim Gower to study seasonal and inter-annual changes of phytoplankton on the coast.
6. Use MODIS (2000 – present) data freely available on the web to map phytoplankton (Borstad is beginning a project in May with a view to improving chlorophyll retrievals close to the coast).
7. Make an Atlas of phytoplankton concentration and sea surface temperature 'snapshots' and time series, for the areas with many aquaculture sites, but also of areas of the north coast where the BC government is considering expanding licencing.
8. Images of turbidity, sediment, chlorophyll and temperature also provide snapshots of circulation patterns.

Crispo, Sabrina. *Department of Earth and Ocean Sciences, University of British Columbia, Vancouver BC.*

Marine geochemistry of cadmium

The depth profile of dissolved cadmium in the open ocean is similar to a nutrient profile in that the concentration in the surface waters is low ($1.1x10^{-4}$-$1.1x10^{-3}$ ppb) and increases with depth (up to 0.11 ppb). The maximum concentration of particulate cadmium occurs at the chlorophyll maximum (depth ~ 100m) but is only 35% of the total cadmium in the surface waters so most of the cadmium is in the dissolved phase (<0.45μm fraction). Speciation of dissolved cadmium affects cadmium's bioavailability to phytoplankton. In surface waters, 70% of the dissolved cadmium is bound to organic ligand(s) thought to originate from phytoplankton. The remaining 30% is mostly bound to chloride, with ~0.9% free (Cd^{2+}). For certain toxic metals, such as copper, some species of phytoplankton have been shown to extrude organic ligands to bind the metal, making the metal biologically unavailable. Since cadmium is considered toxic, the organically bound cadmium may also be biologically unavailable. The concentration of the organic ligand(s) decreases with depth, and in water deeper than 200m, 97% of the dissolved cadmium is bound to chloride, and 3% is in free form.

Since dissolved cadmium increases with depth, cadmium-rich water is brought to the surface during upwelling. Upwelled water comes from depths of 200-400m where the cadmium concentration is 85-250 times higher than surface concentrations. Also, this upwelled cadmium has different speciation than the cadmium in the surface. If the cadmium-binding organic ligand(s) in the surface occur to decrease its bioavailability to phytoplankton, upwelled water is not only enriched in cadmium but is enriched in more toxic cadmium.

The fractionation of cadmium, in deep waters, between the North Altantic and the North Pacific oceans is due to the long residence time of cadmium (60,000 years) compared to the time scale of deep ocean circulation (1000 years) and the assimilation-regeneration cycling of cadmium in the ocean. Deep water formed in the North Atlantic travels south, through the Indian Ocean and ends up in the North Pacific Ocean, making the deep water of the North Pacific the "oldest" deep water. This old water has accumulated cadmium from sinking particles for ~1000 years so the cadmium concentration at depth in the North Pacific is 2-5 times greater than the concentration of the fairly "young" deep water of the North Atlantic.

This oceanic fractionation also affects the amount of cadmium brought up to the surface during upwelling. Upwelled waters in the Pacific have 2-5 times the cadmium concentration of upwelled water from the same depth in the Atlantic.

There is a linear correlation between dissolved cadmium and phosphate ($Cd/PO_4 \approx 0.2$-$0.3x10^{-3}$ mol/mol) that holds true for deep-water profiles. When comparing ratios of different oceans, the trend is the older the water, the higher the ratio.This could be due to preferential uptake of cadmium or faster remineralization of phosphate. Both result in

sinking particles have a higher Cd/PO_4 ratio, resulting in higher ratio at depth when remineralization occurs. Other areas the Cd/PO_4 relationship doesn't always hold is in surface water, estuaries and old upwelled water.

In surface water, the ratio is lower (~ $0.1x10^{-3}$) due to preferential uptake of cadmium or faster regeneration of phosphate. In surface water, it has been found that cadmium uptake is dependent on the available Zn, Mn and pressure of CO_2, which does not control phosphate uptake, thus a decoupling of this relationship in surface water occurs.

In estuaries, cadmium does not have a specific behavior. Considering just speciation, estuaries should be a source of dissolved cadmium from the particulate phase (cadmium should be released from particles when binding to chloride). This release is found in some estuaries, but removal and conservative mixing behavior is also found. Since the behavior of cadmium in estuaries is unpredictable, the relationship with phosphate is decoupled due to other physical and chemical considerations.

In upwelling areas, the Cd/PO_4 ratio of the source water holds true until a plankton bloom occurs. Since coastal waters also have a supply of zinc and manganese, plankton do not require cadmium and thus phosphate is depleted before cadmium and higher ratios result. In areas of low zinc and manganese, the opposite is true; cadmium is depleted before phosphate.

Values of cadmium in the surrounding areas range from 0.045-0.07 ng/g; getting as high as 0.10 ng/g during upwelling and 0.278 ng/g during a storm at Amphitrite Point, British Columbia.

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Nutrient supply along the Northeast Pacific margin

Nutrient supply to the southern B.C. coast is governed largely by winter mixing which fuels the spring bloom, summer upwelling which enriches the exposed coast, and other processes such as tidal mixing, river discharge and katabatic winds which dominate fjords and inland basins. My data shows that ocean stratification has altered nutrient supply to outer coastal waters in recent decades. The 1990s was an abnormally warm decade. Upper ocean warming was observed throughout the region, causing an increase in the stratification of the upper ocean. Strong stratification reduces nutrient supply from the deep ocean to the surface where it can support phytoplankton growth. Since the chemistry of phosphate and cadmium are closely affiliated in open ocean, nutrient dynamics can be used to infer cadmium sources. Upwelled waters will be relatively rich in Cd, as they are in nutrients.

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Mussels as indicators of Cd in upwelling regimes

The oceanic distribution of dissolved Cd is highly correlated with that of nutrients. Thus, upwelled nutrient-rich waters are also rich in Cd. The west coast of Vancouver Island is a recognized upwelling region where strong upwelling events occur in the summer. There is evidence that mussels reflect these Cd-rich upwelled waters since high concentrations of Cd in mussels have been detected on exposed rocky shores during upwelling season.

A study on the Pacific coast of Baja California, México, with samples taken on a monthly basis, clearly showed that the high Cd concentrations detected in the mussel *Mytilus californianus* (up to 17 μg Cd g^{-1}, dry wt) were due to the Cd input from upwelled waters. A Principal Component Analysis (PCA) performed on these data showed the relation of the concentrations of Cd in the mussels with those in brown seaweed (indicators of dissolved Cd) and to upwelling indicators (upwelling index, phosphate, seawater temperature). Other metals (Hg, Al, Mn) did not show any relationship with upwelling. A short-term variability study (samples taken every other day) during the upwelling season showed that this species has the capacity (contrary to other *Mytilus* species) to decrease its Cd concentrations in just few days.

Based on the results from the upwelling region of México, a study on the west coast of Vancouver Island (Amphitrite Point) was carried out to further investigate the capacity of this species to decrease its Cd levels at short periods of time in these regimes. Daily samples of mussels, together with seawater (for dissolved Cd determination, phosphate and salinity) and temperature measurements, were taken during a period of 4 weeks in the summer of 1991. Two upwelling events were detected including a period of high mixing after a strong storm that hit the coast.

Mussels reach up to 9.5 μg Cd g^{-1} (dry wt) during an upwelling event and also increased their concentrations during the period of high mixing. The mussels decreased their concentrations very rapidly after these increases. A PCA on these data showed the relationship of mussel Cd concentrations with the condition index (high loads on Factor 3). However, after accounting for the variability due to the condition index through the use of the Cd/shell wt index, this index showed a very strong relation with dissolved Cd inputs from upwelling (high loads on Factor 1). The capacity of *Mytilus californianus* to release Cd very rapidly appears to be a capacity showed only by this species and at low levels of exposure. This was demonstrated through an experiment in which *Mytilus trossulus* and *Mytilus californianus* were contaminated at two Cd levels and depurated afterwards for few days. At the high Cd level tested, both species increased their Cd concentrations and did not decrease them after being in "clean" seawater for few days. However, at the low level of exposure, while *M. trossulus* did not increase its concentrations at all, *M. californianus* increase its concentrations significantly, to decrease them again to the background levels in just two days.

Higher levels of Cd in *Mytilus californianus* than the one previously mentioned have also been detected on the Baja California coast and have been related to strong upwelling. Levels up to 28 μg Cd g^{-1} (dry wt) have been measured in *Mytilus californianus* during the upwelling season. Cadmium in Baja California oysters (*Crassotrea gigas*) has also been measured from a culture carried out in a coastal lagoon adjacent to an area where upwelling is strong. The oysters exhibited similar Cd levels as the mussels from the adjacent area. The maximum levels detected (up to 16 μg g^{-1}, dry wt) in these oysters occurred in July; a month after the highest mussel Cd level was detected. A short-term variability (samples taken every other day) study on these oysters, carried out over a period of 4 weeks during upwelling season, showed high intrasample variability and only one significant decrease (from 16 to 11 μg g^{-1} dry wt) after four days.

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Cadmium and oysters

Exposure and subsequent accumulation of cadmium by filter feeding bivalves will be dependent on the complex interplay between bivalve pre-selective feeding strategy and seston geochemistry. Bivalves are capable of highly dynamic pre-selective feeding bahavior that will select organic rich particles over inorganic rich particles thus increasing carbon intake. However, at low particle concentrations, bivalves will incorporate both inorganic and organic material as diet. Both laboratory and field based studies have demonstrated that bivalves actively assimilate cadmium from organic matter, and passively from inorganic matter. Under conditions of low seston quantity, bivalves will filter both components from the water column, hence, both components of the seston need to be considered as cadmium exposure routes. Studies on identifying routes of cadmium exposure to suspension feeding organisms should focus on first quantifying the sediment geochemistry of seston from the region the bivalves are actively filtering and then determine field based seston ingestion rates and subsequent assimilation of cadmium from the geochemically characterized seston. Finally, field based elimination rate constants are required to allow for predictions of where and when bivalves such as oysters are at most risk to cadmium exposure through their diet.

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Mechanisms of cadmium sequestration in oysters

Oysters accumulate cadmium through two primary pathways. One is direct uptake by the gill for the dissolved forms of cadmium in the external medium and the other is uptake of ingested material in the digestive glands. Subsequent interorgan transport

results in a tissue level distribution that involves the above organs, the hemolyph, and other internal organs.

The kidney plays an important role in release of cadmium. The concentration of cadmium in the various tissues is determined by the net uptake or loss by each, the integration of which results in the whole body concentration at any point in time. Once taken up by cells in the various organs, cadmium is bound to or sequestered in structures that serve to protect cells from the toxicity of the metal. The most studied systems are the metal-binding protein metallothionein and vesicle-bound granules and concretions. Metallothioneins considered to be metallothionein were first reported in oysters in the species *Crassostrea virginica* (1). The subsequent purification and characterization of these proteins (2) confirmed their identity as metallothionein that had been previously identified in higher animals. This and subsequent work (3), which resulted in deducing the complete amino acid sequence of the cDNA, provided tools in this laboratory for detailed studies on responses of both the protein and its responsible mRNA. Metallothionein is expressed in both adult (see above) and larval (4) oysters. Its expression spares, but does not prevent, binding of cadmium to other structures and related toxicity. Use of antisense oligonucleotides to inhibit metallothionein synthesis has shown that metallothionein in oysters functions to protect against cadmium toxicity (5).

Examination of oysters in natural populations shows that metallothionein-bound cadmium is elevated in individuals exposed to cadmium in the field (6). Cadmium is also reported to occur as granules in granular amoebocytes of Crassostrea gigas (7). Cadmium bound in cellular compartments such as metallothionein and granules are potential sources for uptake by consumers of oysters and also contribute to fluctuations in cadmium concentrations in oyster tissues. The latter is highlighted in studies of *Crassostrea virginica* in which cadmium concentrations can fluctuate over a three-fold range over a two-month period (8). Changes in cadmium levels in the above structure likely account for a significant portion of changes in the whole body cadmium.

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Cadmium in dredge oysters (Tiostrea chilensis) and related species in New Zealand coastal waters

High concentrations of Cd in the dredge oyster (*Tiostrea chilensis*) in the area of Foveaux Strait, at the bottom of New Zealand's South island, have been known for some years (Neilsen, 1975; Frew *et al.*, 1989). Figure 1 tabulates oyster Cd concentrations in New Zealand from the latter two studies and compares them with some results form elsewhere in the world. The very high values in Foveaux Strait (> 5 ppm wt weight) are very puzzling, because this is an almost pristine marine region largely devoid of heavy industries. In particular, there is no Zn or Cd mining or refinement here (or anywhere else in New Zealand).

Recent work in our laboratory (Peake, unpublished data) shows that this anomaly extends to other shellfish species. Figure 2 shows Cd levels in New Zealand scallops (*Pecten novazealandiae*). Note the high values in Paterson Inlet (in Stewart Island, adjacent to Foveaux Strait) and at the Chatham Islands, east of New Zealand.

Figure 3 shows the geography of southern New Zealand in relation to ocean currents. High shellfish Cd levels are observed in all waters affected by the subtropical convergence, which is the oceanographic boundary between warm subtropical waters (e.g. Tasman Current) and cold, nutrient-rich subantarctic waters. Cd concentrations in the ocean are often highly correlated with those of the nutrients nitrate and phosphate (e.g. Frew and Hunter, 1992, 1995) However, although the convergence waters are rich in nutrients, this does not imply high Cd here; indeed, the waters of Foveaux Strait have extremely low Cd concentrations (Frew and Hunter, 1995). This probably indicates very efficient scavenging of Cd from the water column by phytoplankton, and may perhaps be the key to the unusual bioaccumulation of Cd seen in the bivalves.

Figure 4 shows a map of sampling stations used by Frew *at al.* (1997) for an extensive survey of Cd in the Foveaux Strait system. Figure 5 shows more detail of stations occupied around Stewart Island. Oysters were sampled wherever possible, but were generally not found at southern sites around Stewart Island.

Figure 6 shows the histogram of Cd concentrations for all 431 oysters sampled, centred on about 5 ppm wet weight. Figure 7 shows that a major fraction of the Cd is found in the viscera, with least in the muscle tissue.

Figure 8 shows a map of Cd concentrations in the oysters, with the symbol size used to indicate the magnitude of the concentration. The geographic pattern is not especially clear. However, as argued by Frew *et al.* (1992), concentration of Cd in the oyster tissue is not a useful biogeochemical measure because changes take place in the mass of oyster tissue independently of Cd through nutritional state, spawning etc. It is better to

use the Cd uptake rate, calculated by using growth rings in the shell, or the mass per unit area of the shell, to determine the age of each oyster specimen (Frew *et al.*, 1992, 97).

Figure 9 shows the corresponding geographic distribution of the Cd uptake rate. Now it becomes clearer that the greatest uptake rates occur closest to the north of Stewart Island, and generally in deeper waters. Finally, Figure 10 shows the corresponding Cd concentrations in the fine fraction of the bottom sediments. This shows a clear link between high Cd in the sediments and high Cd uptake rate in the oysters.

The origin of the high Cd levels in these oysters remains a puzzle. The "smoking gun" is that water column Cd levels are unusually low, suggesting enhanced Cd uptake by the phytoplankton. If this is true, the rest of the picture, including high Cd in filter-feeding shellfish, would follow naturally. However, it is not at all obvious why Cd should undergo enhanced uptake. Perhaps Cd is substituting for another biologically essential element, e.g. Zn? We need further research to find out.

Are the oysters from Foveaux Strait dangerous to eat? Some years ago, the Department of Human Nutrition at the University of Otago carried out a major study which failed to find evidence of Cd toxicity in individuals eating as many as 4 dozen per day, which corresponds to the daily Cd dose well above that recommended by most health authorities. The answer may lie on the recent finding from our research that a large fraction of the Cd in these oysters appears to be strongly bound to a metallothionein protein that is very stable to degradation, even with heating (Butcher and Frew, unpublished results).

It is clear that while many questions remain, the example of the Foveaux Strait oysters shows:

1. natural populations of oysters, and other shellfish, can, in certain oceanographic regimes, accumulate Cd levels much higher than that normally recommended for human consumption;
2. these oysters seem to be able to sequester Cd in a form that is probably not biologically available.

Clearly we need better information on the types of oceanographic conditions that lead to these anomalous Cd levels, and a more refined way of setting maximum permissible Cd levels that takes account of possible sequestering in non-biologically available forms such as metallothioneins.

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Physical Oceanography of Effingham Inlet

Effingham Inlet located off the Northwest corner of Barkley Sound is a small (~16km long) and narrow (<2km wide) inlet. The inlet has two main basins: a deep (200m) outer basin with a 60m sill and a smaller, and a shallower (120m) inner basin defined by a 40m sill. Tidal currents are generally weak except at the constrictions. Several small rivers discharge into the inlet and the freshwater discharge is assumed to be closely follow the precipitation pattern i.e. high runoff in winter and minimum runoff in late summer and early fall. The often anoxic deep waters of this west coast Vancouver Island inlet have made it the locale for a collaborative multi-disciplinary paleoceanographic study of long-term fish stock abundance and coastal upwelling intensity (Burd and Thomson 2001). Prior to this collaborative study which started in 1995 there were no known publications or data reports for Effingham Inlet oceanography.

An extensive set of water property profiles (temperature, salinity, dissolved oxygen, fluorescence, nutrients and light transmission) from about a dozen oceanographic surveys of the inlet now exist. In the summer, the inlet has strong thermal stratification near the surface, and at times there is no evidence of a freshwater layer. During the winter, the salinity stratification is strongest and the seasonally high runoff produces a thin (0-2m) surface freshwater layer. In 9 of the 12 surveys, anoxic conditions were present in the bottom waters of the inner and outer basins, but anoxia occurred most often in the inner basin. The replacement or flushing of the deep anoxic waters by intrusions of dense oxygenated waters from Barkley Sound are episodic in nature and appear to be related to coastal upwelling events. Renewal events typically occur in summer to late fall and winter is a time of stagnation.

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The general oceanography of BC's coast and the Strait of Georgia as it pertains to Cd enrichment in oysters

The observed enrichment of Cd in oysters from the Northeast Pacific Ocean could potentially be caused by several factors involving either natural cycling of Cd in the earth-ocean system or contamination from human activities or both. To take action aimed at reducing Cd levels in oysters, therefore, requires a clear understanding of the complete Cd cycle as it pertains to a given location. Here, I provide a brief overview of Cd in the ocean, starting at the global scale and focussing down to processes in coastal BC and the Strait of Georgia. Budgets suggest that at the large scale Cd in the oceans is predominantly controlled by natural cycling which includes supply from land by rivers, entry into the productivity-regeneration cycle and, eventually, sequestering into sediments in authigenic sulphide phases (Macdonald et al., 2000). Cd follows soft-body parts in the nutrient cycle and, therefore, mirrors phosphorus in the upper ocean exhibiting depletion near the surface and enrichment below the mixed layer (Figure 1; Bruland and Franks, 1983; Moore, 1981; de Baar et al., 1994). The biocycling of Cd, its relatively long residence time in the ocean (Boyle et al., 1976) and the global ocean conveyor result in the Pacific Ocean being enriched in Cd by a factor of perhaps 5 compared to the Atlantic Ocean (Figure 1). A direct consequence of the global cycle is that Cd will be more of a problem for the North Pacific Ocean than for the Atlantic Ocean and we have no ability to control or change this fundamental fact.

The coast of BC receives Cd enriched water in the same way it receives phosphorus – through coastal upwelling. This process, which places nutrient rich water from the California undercurrent onto the shelf (eg see Mackas et al., 1987; Denman et al., 1981; Figure 2), supplies not only the outer coast but also the inlets and the Strait of Georgia. Tidal mixing in the passages helps to supply nutrient to the surface water of the Strait (cf Harrison et al., 1994) and therefore also Cd.

Numerous rivers along the coast of BC have the potential to supply terrestrial Cd especially where mineralized rocks outcrop. Additionally, contaminant Cd from human activities (industry, agriculture, mining) can enter freshwater systems and thereby transport to the coast. Of note, the largest rivers tend to have large drainage basins that include the coast mountains and BC interior (e.g., the Fraser River). These coastal/interior rivers exhibit freshet during springtime (June; Figure 3) because they are strongly supplied by snow melt. This contrasts the hydrological cycle for rivers on the outer coast of Vancouver Island which are more strongly forced by autumn and winter precipitation (Figure 3) and we can accordingly expect coupling between riverine input of Cd (particulate and dissolved) and the oyster growth cycle to vary depending on location. This may be an important factor in Cd enrichment especially if particulates

provide a pathway to concentrate Cd and deliver it to oysters during feeding (see, for example, McConchie and Lawrance, 1991).

Within the Strait of Georgia, the Fraser River dominates the runoff and particulate supply (Milliman, 1980). Observations show that the Fraser River has generally lower Cd concentrations than the salt water of the Strait (about 20 ng/L vs 70 ng/L; Figure 4; Fletcher et al., 1983) and, although we do not know the availability of this Cd to biota, there is no reason to suspect the Fraser River as a major source of Cd enrichment. Many of the oyster harvesting regions – especially those exhibiting high Cd concentrations – are located toward the north end of the Strait of Georgia. Depending on winds, the Fraser Plume can travel to the north (Figure 5; Stronach et al.,1988; Thomson, 1981) but it is often seen spreading to the south (Figure 6; Gower, pers. comm) and most of the Fraser River water eventually escapes the Strait of Georgia into the Strait of Juan de Fuca via the southern passages (LeBlond, 1983; Thomson, 1981). Sediment traps moored during a two year period at three sites in the Strait of Georgia (Figure 7) show that particulates from the Fraser Plume tend to be deposited off the Fraser River or to the south; northern transport seems to be very much smaller (Figure 8; Macdonald et al., unpublished).

Municipal outfalls are another potential source of Cd to the Strait of Georgia. Based on Ag (Gordon, 1997) and nonylphenol ethoxylates (Shang et al., 1999), the sedimentary footprint for the Iona outfall (Figure 9) is confined to a 40 km^2 area off the Fraser delta. Other outfalls, particularly those discharging near the surface, might have an opportunity to spread contaminants in surface waters over a greater distance, but it seems unlikely that the regions exhibiting high Cd in oysters (north end of the Strait of Georgia) would be vulnerable to these sources which are distributed predominantly near the south end of the Straits.

Cd profiles in dated sediment cores from the Strait of Georgia and Juan de Fuca show little evidence that could be interpreted as contaminant Cd input (Macdonald and Crecelius, 1994; Macdonald et al., 1991; Matsumoto and Wong, 1977; Pedersen et al., 1989). Macdonald et al. (1991) estimated the residence time for Cd in the Strait of Georgia to be greater than 10 years (Figure 10) which is much longer than the 0.5 to 2 years taken to exchange the water (Waldichuk, 1957). This implies that Cd entering the Strait of Georgia either from ocean exchange or from land-based sources tends to mix and transport through the system rather than accumulate in the water or become captured on particles or in sediments. Sediments, therefore, appear not to be suitable recorders of "dissolved" Cd and therefore would poorly reflect contamination should it have occurred. Where Cd enters the system as a particulate (e.g., sulphide mineral phase in mining), burial in sediments may be recorded and once sediments become sulphidic, the strong affinity of Cd for sulphide phases will tend to lock it in place. However, uptake of particulate Cd is possible if animals are foraging on the contaminated sediment (Burd et al., 2000). Curiously, Cd sediment enrichments of up to 8 μg/g have been observed in Ucluelet Harbour sediments (Figure 11; Pederesen et al., 1989) – far from any obvious contaminating sources. Geochemical evidence supports a natural enrichment mechanism that includes upwelling of Cd-rich water, organic carbon

fluxes to sediments sufficient to produce anoxic and sulphidic conditions very close to the sediment surface, and diffusion of Cd into the sediments followed by precipitation within sulphide phases. This mechanism of sequestering Cd is widely distributed in marine sediments and controlled by redox conditions which themselves are controlled by sedimentation rate and organic carbon flux (see Gobeil et al., 1997). Although this process of Cd enrichment is natural, it could lead to enhanced amounts of Cd in oysters if, for example, beach sediments were to go anoxic just below the surface (which is often evident from sulphide smell of tidal flats and the black appearance of buried sediment). Cd-rich particles, produced in these anoxic environments, could later be resuspended by wave action, filtered out by oysters, and the Cd released during digestion. Particles have been shown in certain cases to act as a transport medium for Cd (McConchie and Lawrance, 1991), and correlations between sediment and oyster Cd concentrations (cf. Peter Thompson, these proceedings) support such a mechanism under the right circumstances.

Enrichments of elements or compounds in biota usually occur not because of a single factor but, rather, because several factors act together. For the Cd enrichments observed in wild and cultured oysters of the Northeast Pacific Ocean we understand only a couple of the conspiring factors. In particular, the Pacific Ocean contains relatively high baseline concentrations of Cd and upwelled water that feeds the primary production of the coast supplies Cd at the same time. Furthermore, oysters have a physiology that makes them particularly susceptible to concentrate and retain Cd (Engle, 1999). The first factor we cannot change and the second factor would require the development of oyster stocks that are less susceptible to Cd uptake or more able to depurate Cd. Other factors that are presently poorly understood or not understood at all include: 1) Coupling between particles, Cd and oysters; 2) The interaction of runoff and oyster feeding (timing, particle supply, stratification); 3) The interaction between other elements (Zn specifically) and Cd in the biogeochemical cycle (e.g., see Rouhi, 2000; Loscher et al., 1998); 4) The seasonal cycle of Cd uptake by oysters; 5) Natural enrichment of Cd due to drainage basin geochemistry; 6) Enhanced Cd cycling due to basin disturbance (logging, construction); and 7) Contamination from human activities (municipal outfalls, pulpmills, street runoff; mining (acid mine drainage); industry (paint, electroplating); agriculture and silviculture (phosphate fertilizer in particular). Given the locations of oysters exhibiting high Cd concentrations, contaminant sources such as industry, street runoff, and municipal outfalls seem unlikely.

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Some Comments on the General Oceanography of the Northern Strait of Georgia and Inlets

Many investigators (Waldichuk 1957, Thomson 1994) have studied the Strait of Georgia, however most of the studies and sampling have focused on the southern portion of the strait and the influence of the Fraser River. In fact, only about 15% of all samples from the Strait of Georgia have been collected from the northern half. The observations from the northern strait show that it is also affected by the highly seasonal discharge of the Fraser River. Near surface salinities are low in summer but not as low as in the southern strait, though the Fraser River plume, given appropriate wind and tides, may be driven northward. Most of the freshwater that enters the strait exits through the southern passages because in terms of cross-sectional area, the

northern passages (Discovery Passage, Yuculta and Arran Rapids) are quite small (only 7%) compared to the southern passages through the Gulf and San Juan Islands.

Little is known about the detailed circulation of the northern strait. In general terms, tidal currents are weak (<10 cm/s) except near the constricted tidal passages at the northern boundary of the strait, and there is a rumoured counter-clockwise circulation. South of Discovery Passage waters move southward along the east coast of Vancouver Island and northward along the mainland coast.

Several large inlets adjoin the northern strait, and of these Bute and Jervis Inlets are the largest and best sampled. Jervis and Bute inlets have some similarity in physical attributes but have quite different watersheds and hydrologic cycles. Bute Inlet's water shed area is much larger and drains interior snow fields and glaciers. Bute Inlet's largest river, the Homathko, discharges at the head of the inlet and has a flow pattern similar to that of the Fraser River, though its peak discharge is about one month later. Jervis Inlet has a smaller watershed and freshwater flow. The streams entering Jervis Inlet are distributed along the length of the inlet, and their runoff more closely follows the coastal precipitation pattern and snowmelt in the local mountains. This difference in the amount and timing of the freshwater discharge is reflected in the near surface temperature and salinity cycles of these two fjords. During the summer, Bute Inlet near surface salinity is much fresher (5 to 15 PSU) and temperature much colder (10 to 12°C) than in Jervis Inlet where salinities of about 20 PSU and temperatures of 17 to 20°C are observed. The Desolation Sound area and Pendrell Sound are in close proximity to Bute Inlet and the energetic tidally mixed northern passages, yet some of the warmest waters of the coast occur in this region. The combination of weak tidal currents, very small local freshwater flow and weak winds allow solar insolation to heat the surface water of Pendrell Sound without much mixing and flushing.

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Cadmium in Pacific oysters

The cadmium that is found in Pacific oysters (*Crassostrea gigas*) from British Columbia (Canada) must come from some source. In this Abstract I argue that this source is mostly likely natural and that the vector is phytoplankton.

Dissolved inorganic Cd appears to behave like a nutrient in oceanic waters. In general it is depleted in surface waters in pattern to similar to [PO_4] (Bruland 1983). Recent research has provided strong evidence that Cd is indeed a nutrient used by phytoplankton (Cullen et al 1999, Lee and Roberts 1995, Payne and Price 1999).

There are several methods that can be used to estimate the possible content of Cd in phytoplankton: 1) from empirical ratio data (e.g. Redfield 1958), 2) from laboratory experiments on Cd content (e.g. Lee and Roberts 1995), 3) from field and laboratory data on the factors that may influence the amount of Cd incorporation (e.g. Sunda and Huntsman 1998, Payne and Price 1999).

From empirical data we can estimate the possible Cd incorporation as from observed water chemistry for the Northeast Pacific (relatively high PO_4 in upwelled water) and Redfield ratios for phytoplankton composition we can estimate the molar C:N:P:Cd rations which should be approximately 318000:48000:3000:1. Given a dry weight (dw) to carbon ratio of about 2:1 and converting to weights (from molar ratios) the expected dw:Cd content of phytoplankton in the NE Pacific could be as high as 15 ppm. Assuming 1:1 incorporation by oysters then phytoplankton at 15 ppm could be expected to yield oysters at about 2 ppm Cd on a wet weight basis.

From laboratory research on the diatom *Thalassiosira weisflogii* the Cd quota of cells varied. Making the assumptions that C:P was 106:1 and dw:C was 2:1 then the range of dw:Cd ratios observed in culture was 0.4 to 14 ppm depending upon culture conditions (Lee and Morel 1995, Lee and Roberts 1995). The Cd was clearly bound in association with carbonic anhydrase.

Factors that could increase Cd content of phytoplankton cells include:

1. Concentration of Cd in water (Payne and Price 1999). For some species Cd quota was a strong positive function of [Cd].
2. Low Mn, low Zn and low CO_2. Because of the physiological uses of Cd within cells low concentrations of any of Mn, Zn, and CO_2 have been shown to result in an increase in Cd quota in a number of phytoplankton species. The details of how and, to a certain extent why, these influence the Cd quota of phytoplankton cells are given in Sunda and Huntsman (1998) and Cullen et al. (1999). For the purpose of this forum the fact that the Cd cell quota can vary significantly and that this variation is related to variability in other environmental factors is important. It provides another mechanism to explain spatial and temporal patchiness of Cd in oysters.
3. Association of Cd with Ca. Due to similar size and charge Cd replaces Ca in Foraminifera (van Geen and Luoma 1999). It seems quite likely that this would also happen in Coccolithophorids. Indeed over a range of phytoplankton Classes the greatest quota of Cd was observed in coccolithophorids by Payne and Price (1999).
4. Based on its distribution in the water column it seems reasonable to assume that Cd recycles on a similar time scale to PO_4. Given the seasonal dynamics of PO_4 concentrations in temperate coastal ecosystems there is likely to be a strong

seasonal component to the concentration of Cd in phytoplankton (in the particulate phase).

In conclusion, phytoplankton are a likely vector for Cd in filter feeding bivalves (including commercially harvested oysters). High nutrient (possibly upwelled) waters are likely to contain sufficient Cd to result in phytoplankton containing relatively high Cd concentrations sufficient to explain Cd concentrations in oysters in excess of 2 ppm (wt weight). Factors such as different phytoplankton species and growth conditions can change the Cd concentrations in phytoplankton cells by a factor of ~10.

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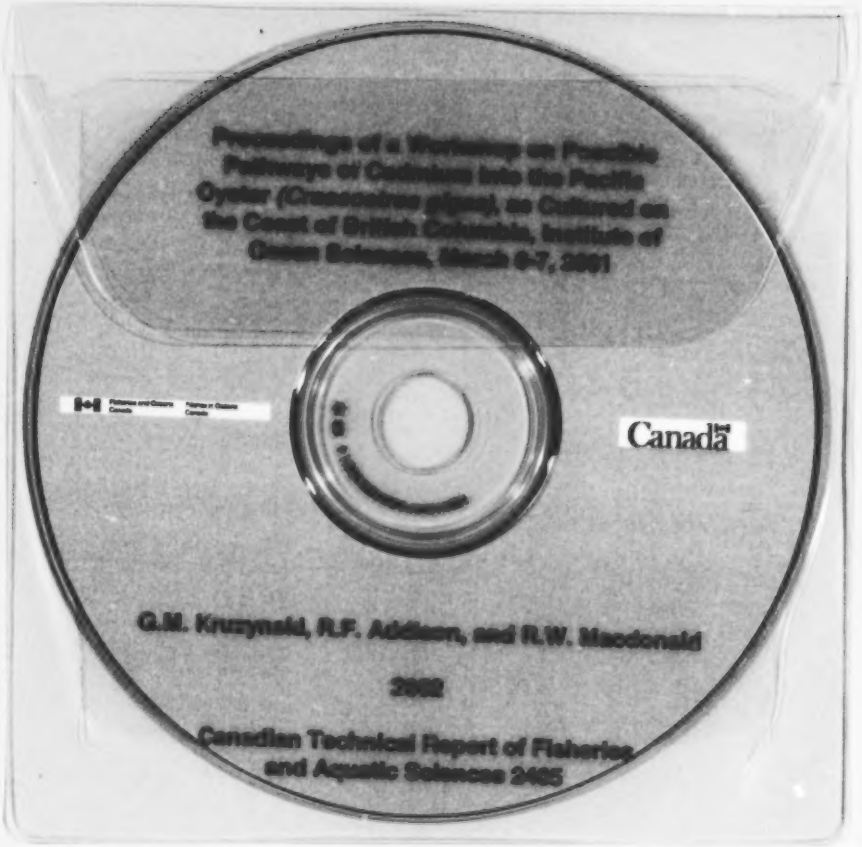
APPENDIX C: CADMIUM RESIDUE WEIGHTS

Comparison of Cadmium residue dry vs wet weight basis based on ~85% moisture.
Bold represents at or over the 2 ppm (Hong Kong limit)

μg Cd/g dry weight	μg Cd/g wet weight
35	**5.25**
34	**5.1**
33	**4.95**
32	**4.8**
31	**4.65**
30	**4.5**
29	**4.35**
28	**4.2**
27	**4.05**
26	**3.9**
25	**3.75**
24	**3.6**
23	**3.45**
22	**3.3**
21	**3.15**
20	**3**
19	**2.85**
18	**2.7**
17	**2.55**
16	**2.4**
15	**2.25**
14	**2.1**
13	**1.95**
12	1.8
11	1.65
10	1.5
9	1.35
8	1.2
7	1.05
6	0.9
5	0.75
4	0.6
3	0.45
2	0.3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